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European Journal of Medical Physics

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Supplement Issue
Abstracts of the
4th European Congress of Medical Physics

17–20 August 2022
Dublin, Ireland

Editor-in-Chief: Iuliana Toma-Dasu
Past Editors-in-Chief: Paolo Russo and Fridtjof Nüsslin

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Aims and Scope

Physica Medica, European Journal of Medical Physics, provides an international forum for research and reviews on the main topics related to the major areas of scientific and professional activities of medical physics:

Radiation Therapy
Diagnostic and Therapeutic Nuclear Medicine
Diagnostic and Interventional Radiology
Magnetic Resonance Imaging and other non-ionising imaging modalities.

Contributions to the below related fields complementing the major topics are also encouraged:

Radiation Protection
Radiation and System Biology
Artificial Intelligence in Medical Physics.

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Education and Training in Medical Physics
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17–20 August 2022, Dublin, Ireland

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Abstracts of the 4th European Congress of Medical Physics

KEYNOTES /Joint Session Speakers

600
BASICS OF PHOTON COUNTING CT

Marc Kachelriess[1]

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Conventional CT systems are equipped with indirectly converting detectors where an x-ray photon interacts with a scintillator material where its energy is converted into visible light photons which, in turn, interact with a photo diode that produces a current proportional to the number of visible light photons. Such detectors are thus also called energy integrating detectors. The sensor material typically is GOS in clinical CT and CsI or GOS in flat detector systems. Just recently, direct converting detectors have been introduced into clinical CT. These photon-counting detectors directly convert the x-ray photon energy into an electric signal. They do so using a semiconductor material as the sensor layer. Typically, the sensor material is CdTe or CZT. The signal charge is proportional to the photon energy and the signal duration is short enough to be able to count single photons. Moreover, each detector pixel is equipped with more than one comparator and thus allows to distinguish between photons of different energies. Thus, spectral information, similar to dual energy CT, is routinely acquired and can be used retrospectively on demand.

This short lecture provides some technical overview of photon counting detectors and then describes the many advantages of such systems: better dose efficiency, higher spatial resolution, spectral information, small pixel effect, iodine effect, etc. The lecture reports on measurements with the first whole-body photon counting CT prototype (Somatom CounT, Siemens, Healthineers) system and with the first clinical photon counting CT system (Naeotom Alpha, Siemens Healthineers), which is a dual source CT system. Comparisons to conventional energy-integrating CT are provided, wherever possible.

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A JOINT INTERNATIONAL EFFORT: REPORT ON TG359

Prof Dimitris Mihailidis[1]

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Flash radiotherapy (FLASH-RT) has been moving fast forward with variety of treatment modalities (protons, electrons, heavy ions) and the accurate treatment delivery for this modality needs to be warranted. Understanding the dosimetry of these ultra-high dose rate (UHDR) and dose output per beam pulse beams is necessary for developing robust beam calibration procedures.

With the rapid translation of FLASH RT into the clinic, academic institutions are eager to investigate FLASH mode effects via cell irradiation and small animal research. In these conditions, a large amount of dose is delivered in a very small amount of time (e.g., 20 or more Gy in <0.5s) that, we believe, needs careful understanding and accurate calibration verification and potentially, quality control. Clinical trials will require an accurate reference dose measurements and common language to characterize these new beams. The traditional dosimetry methods using ionization chambers will be carefully investigated for applicability and potential modification to fit the UHDR conditions. New type and improved technology detectors are on the way to bridge the gap.

The AAPM Task Group 359 (FLASH (ultra-high dose rate) dosimetry) was approved in 2021 as a joint venture between the AAPM and EFOMP some of them as members of ESTRO-ACROP and members from other international institutions. The focus of the task group has been on beam dosimetry issues of Flash beams, suitability of radiation detectors and existing calibration methods and dosimetry standardization.

The structure of the task group, coordination process of its large membership and current status of the report will be presented.

Objectives: 1) Underline the complexity of and variations in defining dose rate and their impact on beam dosimetry and metrology for UHDR beams. 2) Describe the dosimetric challenges that may exist under UHDR regime. 3) Describe the mechanism of coordination in a large joint task group.

602
OUT-OF-FIELD DOSES AND ASSOCIATED RISK OF CANCER IN RADIOTHERAPY

Dr Michalis Mazonakis[1]

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The survival rate of cancer patients has considerably increased the last decades. Radiation therapy plays a major role in the cancer management. The use of advanced irradiation techniques enables the delivery of conformal and high doses to the tumor site leading to an improved tumor control. Despite the high conformity, the tissues excluded from the treatment volume are always exposed to ionizing radiation. The harmful radiation effects to out-of-field healthy tissues is always a concern for the growing population of the cancer survivors. Radiation-induced second malignancies may be presented in organs and tissues located in the near or far periphery of the treatment volume.

The organ-specific dosimetry is required for estimating the second cancer risk associated with radiation therapy. Dosimetry studies directly combine the out-of-field organ doses with data derived from the proper risk models to theoretically estimate the organ-specific

or whole-body probability of carcinogenesis. Epidemiological studies provide useful information about the second malignancies through the long-term follow-up of patients subjected to radiation therapy. The epidemiological data need to be used together with the results of the organ-specific dosimetry for the appropriate risk analysis. This presentation focuses on the methods of out-of-field cancer risk assessment in radiation therapy. The uncertainties and limitations of these approaches are described. The impact of several factors, related or unrelated to radiation therapy, on the probability of out-of-field cancer induction is presented.

604
LOCAL CLINICAL DRLS: A TEN STEPS METHODOLOGY
Hugues Brat[1]

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Purpose: How to set up sustainable Local clinical DRLS (LcDRLs) in a multicenter setting.
Objectives: 1. To understand the clinical relevance of LcDRLs. 2. Ten steps to achieve sustainable LcDRLs. 3. Challenges to achieving sustainable excellence.
This presentation proposes a practical approach to setting up local clinical DRLs in 10 steps, with a collaborative methodology that does not impair radiologists' clinical routine.
Once established, LcDRLs should be considered a dynamic tool, keeping up with technology and clinical developments. Therefore, sustainability and continuous quality assurance are teamwork, including at least a radiologist, a medical physicist, and a radiographer.
Take home: Using local DRLs as a continuous quality improvement tool enables implementing a dose reduction culture by guiding radiologists, medical physicists, and radiographers towards a change of practice to deliver the right dose for the right diagnosis and achieve excellence in terms of quality and safety in medical imaging.

605
HOW CAN AI IMPROVE RADIATION PROTECTION IN MEDICAL IMAGING?
Habib Zaidi[1]

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Modern techniques including X-ray computed tomography (CT), single-photon emission computed tomography (SPECT), positron emission tomography (PET), and magnetic resonance imaging (MRI) as well as their combinations (SPECT/CT, PET/CT and PET/MRI) provide powerful multimodality techniques for in vivo imaging. Yet, the radiation risks from medical imaging examinations are still a matter of concern.This talk presents the fundamental principles of multimodality medical imaging and reviews the major applications of artificial intelligence (AI), in particular deep learning approaches, in medical radiation protection. It will inform the audience about a series of advanced development recently carried out at the PET instrumentation and Neuroimaging Lab of Geneva University Hospital and other active research groups. To this end, the applications of deep learning in five generic fields of medical radiation protection, including imaging instrumentation design, image denoising (low-dose imaging), image reconstruction quantification and segmentation, radiation dosimetry and computer-aided diagnosis and outcome prediction are discussed. Deep learning algorithms have been widely utilized in various medical imaging problems owing to the promising results achieved. This talk reflects the tremendous increase in interest in optimizing medical radiation protection using deep learning techniques in the past few years. The deployment of AI-based methods when exposed to a different test dataset requires ensuring that the developed model has sufficient generalizability. This is an important part of quality control measures prior to implementation in the clinic. Novel deep learning techniques are revolutionizing clinical practice and are now offering unique capabilities to the clinical medical imaging community. Future opportunities and the challenges facing the adoption of deep learning approaches and their role in radiation protection research are also addressed.

606
COMMISSIONING AND PLANNING OF TREATMENT PLANNING SYSTEMS FOR SELECTIVE INTERNAL RADIATION THERAPY
Dr Lidia Strigari[1]

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The adoption of molecular radionuclide therapy (MRT) in clinical contexts widely increased during the last years. The implementation of dosimetry has gained growing interest in MRT treatments to guide MRT treatment and fulfil the EURATOM directive 59/2013.
Personalised dosimetry is a time-consuming procedure requiring acquiring one or more patient images, typically using hybrid baseline CT images, SPECT/CT or PET/CT, and employing ad hoc methods to translate images in dose distributions at the organ, volume or volume voxel level.
Dedicated Treatment Planning Systems (TPSs) are available to assist medical physicists in performing dosimetry Selective Internal Radiotherapy (SIR) treatment with 90Y or 166Ho.
Our work investigates the main steps for commissioning and implementing treatment planning for the available commercial TPSs for SIR.
Although the workflow can differ from one TPS to another, typical steps required to generate absorbed dose distributions include A one-off calibration procedure using phantoms or virtual images, DICOM image import, Volumes of interest (VOIs) contouring/propagation, Image registration for organ segmentation or pre and post-treatment comparison, VOIs propagation between time-points, Tools for absorbed dose distribution evaluation and reporting. Moreover, each TPS might be equipped with optional tools, including automated or assisted contouring or file management in DICOM RTstruct and RTdose format.
In addition, image correction can be applied to improve the dose calculation accuracy, thus producing robust dose-effect predictions. Although the number of TPS installed and adopted in a clinical context for personalised dosimetry increases, a systematic assessment and harmonisation of the TPS commissioning phase is still needed.
The talk aims to report an attempt to harmonise the results of TPSs adopted in the clinical context for SIR.

607
DETECTORS FOR NEXT GENERATION PET AND SPECT
Stefaan Vandenberghe[1]

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Improving PET and SPECT detector is closely coupled to system design and a compromise between resolution, sensitivity, field of view and cost. Typically an improvement in one of those will affect the others in a negative way for a gamma camera. An alternative for Anger camera are semiconductors. These are however more expensive and require other designs.
New SPECT designs are typically based on multipinhole configurations or parallel hole collimated detectors which can rotate

('swivel') around their own axis. By using high resolution detectors and multipinhole detectors we need less magnification to get the same resolution in the object. The situation is somewhat different in PET. An improvement in resolution, sensitivity or FOV will not affect the others in a negative way like in a gamma camera. It is relatively easy to improve PET by adding more detectors/rings. New detector concepts can improve spatial and TOF resolution. Deep learning is also used to reduce dose and can also be implemented to go towards more cost-effective designs.

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CURRENT STATUS OF DOSIMETRY IN FLASH RADIOTHERAPY: SUITABLE DOSIMETERS TO USE IN UHDR IRRADIATIONS

Anna Subiel[1]

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Ultra-high dose-rate (UHDR) irradiations, known as FLASH radiotherapy (RT), rely on delivery of therapeutic doses at instantaneous dose-rates over four orders of magnitude higher than those currently used in conventional radiotherapy. It has been shown that such an extremely short delivery of radiation leads to remarkable reduction of normal tissue toxicity with respect to conventional dose-rate RT. Given the size of the error of biological contributions in radiotherapy outcomes, it is important that the physical errors are minimized. According to ICRU Report 24 a change of 7–10% in dose to target volume results in clinically significant change in tumour control probability. Therefore, it has been agreed that there is a requirement for an accuracy of ±5% (k=2) in the delivery of absorbed dose to a tumour volume. These dosimetric constraints are fulfilled in conventional radiotherapy, where dosimetry methods and protocols have solid foundations. However, dosimetry at ultra-high dose-rate is complicated and it is essential to understand the effects that will influence detector response. To date, FLASH RT research has been focused on finding pragmatic solutions that allow the use of UHDR beams in the research setting, but there has been limited focus on accurate dosimetry for FLASH RT. There are limited data on the functionality of existing standard dosimeters when they are used to measure beams delivered in UHDR mode, hence it is essential to evaluate whether these dosimeters are appropriate when used in UHDR regime. Given that the FLASH RT field is moving forward very fast, with the first clinical trials already commenced, it is of the utmost importance to ensure safe delivery of this new treatment modality to the patients. Without a clear understanding of the fundamental dosimetry issues, there is potential for significant dosimetric errors. One of the examples of dosimetric challenges that need to be approached in FLASH RT, are non-negligible ion recombination effects exhibited by ionization chambers when operated at UHDR regime. Other detectors such as films and alanine, both of which require post-irradiation processing, are not practical for regular use in clinical practice. Therefore, there is a quest to develop new detectors which could act as reliable and accurate dosimetry devices in FLASH RT. Developments such as microdiamonds, ionization chambers with very small electrode separation and calorimeters seem to be the most promising candidates for the UDHR dosimetry and will be discussed during this talk.

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FOETAL DOSE ESTIMATION FROM ADMINISTRATION OF RADIONUCLIDES. EXPOSURE LEVELS. DOSIMETRY AND IMPLICATION

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The radiation risk throughout the pregnancy is related to the absorbed dose to the embryo or foetus. The risk is also related to the stage of pregnancy at the time of irradiation.

In nuclear medicine, diagnostic or therapeutic, radioactive substances are administered to the patient to demonstrate or exclude pathologies or diseases or for therapy and follow-up of treatment. The activity is after the administration distributed within the whole body of the patient and in the case the patient is pregnant the foetus will be irradiated externally from activity in the mother. Some radiopharmaceuticals cross the placenta and concentrate within the foetal tissues resulting in an internal exposure of the foetus.

The magnitude of the absorbed dose to a foetus depends on which nuclear medicine procedure is carried out since the dose depends on the biodistribution and retention of the activity in various organs and tissues of the mother as well as on the excretion routes. If a placental crossover is present, this also affects the dose. The physical parameters of the radionuclides such as physical half-life, the type of radiation and the energy emitted from the radioactive decay are fundamental for the determination of the dose.

The absorbed dose to the foetus is not easily determined. However, there are scientific literature presenting dose data based on simulations using reasonable assumptions and realistic computational phantoms for early pregnancy, first, second and third trimester.

For most diagnostic nuclear medicine procedures radiopharmaceuticals labelled with short-lived radionuclides are administered. In these cases, the radiation risk to the foetus is minimal and the radiation exposure is usually medically appropriate. There are however exceptions, there are examples when the foetal exposure will result in significant harm to the foetus after administration of radiopharmaceuticals to the mother. Therapy of thyroid malignancies using sodium iodide labelled with iodine-131 can serve as such an example. Thus, it is important to know how to determine and minimize the foetal dose for different nuclear medicine procedures and to put the radiation risk in perspective to the need of the examination of the mother.

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DATA SCIENCE IN ONCOLOGY – TOWARDS A LEARNING HEALTHCARE SYSTEM

Dr. Ir. Jennifer Dhont[1], Prof. Dr. Nick Reynaert[1]

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The past decade has witnessed an unprecedented pace of developments in healthcare, and oncology specifically. Through the introduction of multiple novel technologies and multi-disciplinary approaches in both patient characterization, diagnosis, and treatment, we are closer than ever to the promise of personalized medicine. However, at the same time, there is an inadequacy of the evidence to keep up as clinical trials recruit only a very limited and highly curated percentage of patients, often answering the research question long after there was any interest.

As a result, we currently lack the necessary evidence to identify the most promising or appropriate treatment pathway on an individual level. To overcome this challenge, it is clear that we must reengineer the way evidence is generated and applied.
For more than a decade, many have argued for the concept of a learning healthcare system or rapid learning. In this scenario, discovery and innovation is driven as a natural product of patient care through the systematic recording and automatic analysis of real-world data. To this end, radiation oncology, one of the most computerized medical specialties, lends itself as an ideal candidate to pioneer this novel approach in evidence-based medicine. In addition, while the utilization of complex electronic health information technology presents unknown terrain for most clinical healthcare personnel, it is familiar playground for medical physicists, especially for those with an affinity for computer- and data science.
Multiple radiation oncology patient registries have already been created in hospitals throughout Europe and America, including international initiatives to link these registries for distributed learning purposes. However, while we have succeeded in crossing country boarders, we very often remain stuck within the walls of our own radiotherapy department. The number of departments and (research) laboratories involved in modern anticancer treatment can be numerous, from those specialized in pathology, immunology, genetics and hematology to surgery, radiation, and medical oncology. Nevertheless, outside a clinical trial context, to generate new hypothesis and gather evidence data is rarely shared between these specialties. This despite the non-negligible mountain of evidence on the added value of a multi-disciplinary and translational approach to medicine.
In this presentation, the broader role of data scientists within the department of medical physics, bridging multiple disciplines within an oncology hospital, will be discussed. The development and implementation of a learning healthcare system for both prospective and retrospective studies in our institute will be used as a real-life example.

611
OPEN SOURCE SCRIPTING IN MODERN TPS

Jakob Ödén[1]

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The aim of this talk is to give an overview of open source scripting in modern radiotherapy treatment planning systems (TPSs). A scripting language is in this context a tool to programmatically communicate with the TPS through a scripting application programming interface (API) without having access to the source code itself. Scripting languages are usually, but not exclusively, interpreted at runtime rather than compiled, and may automate the execution of tasks that would otherwise be performed individually by a human operator. Through programming languages such as C++, C# and Python users can access and edit data in the TPS, perform user interface actions which normally are performed with multiple mouse clicks and/or keyboard inputs, and much more. The scripting language can also support the creation of graphical user interfaces as well as export data using common output format such as csv, pdf, txt and xlsx, which then could be imported into third-party software for further analysis. This opens a vast number of opportunities including automation of repetitive tasks, customisation of clinical workflows and quality controls, advance data analysis, data visualization etc. Such scripting features are commonly used to improve the daily clinical routine worldwide and is also instrumental in several research studies related to radiotherapy. In this talk, the clinical and research use of scripting languages will be demonstrated through examples of published studies where scripting has been an essential tool as well as demonstrations of specific examples of what you can achieve with scripting even with limited programming experience.

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MONTE CARLO FOR RADIATION THERAPY

Michael Fix[1]

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Monte Carlo (MC) methods allow simulating the radiation transport from first principles including the transport of created secondary particles. Consequently, this technique is perfectly suited for accurate modelling in the field of medical physics and specifically in radiation therapy. Initially being a powerful research tool, the MC method has become omnipresent in clinical radiation therapy over the last couple of decades. This is being demonstrated by the large number of publications, the number of developed MC codes and user packages as well as applications implemented in commercial products. This includes but is not limited to beam modelling and characterization, dose calculation and optimization and dosimetry in external beam radiation therapy as well as in source characterization and dose calculation in brachytherapy.
To some extent the increased use of MC methods in radiation therapy is due to the enormous increase of available computation power as well as of efficient and powerful software tools. However, applications still suffer from long simulation times due to the raising demands of the problems to be solved as for example in the field of radiobiology to better understand the underlying mechanisms of radiation at the cellular level. This also demonstrates the continuous evolvement of MC techniques and MC codes needed to tackle the upcoming challenges. Thus, it is expected that the MC techniques simulating the radiation transport will continue to grow in radiation therapy.
The two objectives of this refresher course are to understand the concept of the MC method and to learn how to apply MC in the field of radiation therapy. The first will be explored on a simple example by means of a do-it-yourself code, while the second introduces a generally applicable recipe. This recipe is demonstrated on a typical use case in order to illustrate the main steps. Hence the course will provide the basics of MC in radiation therapy for newcomers in the field, while it will provide a refresher summary for the others.

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A SUGGESTED RATIONAL SCHEME FOR ROLES FOR THE DIFFERENT PROFESSIONS IN MEDICAL RADIATION PROTECTION

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Owing to the heterogeneity of educational levels, professional titles and legal professional responsibilities of the various professions involved in medical radiation protection in Europe the European Council in its Directive 2013/59/EURATOM defined roles but did not link said roles to the various traditional professions. This approach has the advantage of flexibility - however, it has also created ambiguity and sometimes conflict between the professions to the detriment of both patients and the professionals themselves. To help resolve the problems the EU has invested a lot of money and effort in such projects as the European Guidelines on the Medical

Physics Expert and the ENETRAP projects. However, it is up to us the leaders of the different professions to agree between us on a European scheme to apportion these roles among the different professions to give us all direction, to ensure safety for all, harmony between the professions and a happy environment at our places of work. This presentation suggests a simple rational scheme based on the guidelines of the aforementioned European projects and the different strengths of the various professions to help drive the discussion forward.

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ACCEPTANCE AND QUALITY CONTROL (QC) OF PHOTON COUNTING COMPUTED TOMOGRAPHY (PCCT) SYSTEMS

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PCCT enables differentiation, quantification and classification of different types of tissues. In order to ensure the accuracy and reproducibility of PCCT data and associated applications in clinical practice, additional acceptance testing and a dedicated QC program are needed. This course addresses the following topics: 1) phantom requirements for spectral imaging; 2) dose and (traditional) image quality assessment; 3) from basic system performance to operational performance; 4) imaging artifacts; 5) international initiatives and standards on multi-energy CT.

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THE MAYO CLINIC EXPERIENCE TREATING PATIENTS WITH SPATIALLY FRACTIONATED RADIATION THERAPY

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Spatially Fractionated Radiation Therapy (SFRT), often referred to as "grid" therapy, is the intentional delivery of a highly heterogeneous dose distribution consisting of alternating regions of high dose "peaks" immediately adjacent to low dose "valleys". SFRT is often delivered in a single fraction where the peak doses range from 15-20 Gy and the valley doses are typically 3-5 times lower. The high focal doses are meant to safely and effectively debulk large tumors while the low dose regions help to limit normal tissue exposure and toxicity. Additionally, the highly non-uniform dose distributions are thought to potentially induce a number of anti-tumor responses but the radiobiological mechanisms involved are poorly understood. Despite only partially irradiating the tumor to high doses, SFRT can be a remarkably effective treatment option resulting in excellent tumor control and regression along with prompt pain relief for patients having bulky and/or radioresistant tumors.

This talk will give an overview of the Mayo Clinic experience treating patients with SFRT. I will describe the various treatment methods we use and provide physics guidance for those wishing to implement these techniques.

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OUT-OF-FIELD DOSES IN PHOTON AND PROTON THERAPY IN CASE OF PAEDIATRIC PATIENTS – LESSONS LEARNT FROM EURADOS INTERCOMPARISONS

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EURADOS WG9 (Radiation Dosimetry in Radiotherapy) has been engaged since 2010 in different measurement campaigns designed to investigate secondary radiation doses inside paediatric anthropomorphic phantoms exposed to scanning proton radiotherapy. The results were comapred with previous experiments performed for different photon radiotherapy modalities [1,2]. Firstly, WG9 performed detailed characterization of the out-of-field doses, associated with proton PBS in a water phantom with both measurements and MC simulations. In the second step, measurements of out-of-field organ doses in realistic clinical conditions were performed inside child anthropomorphic phantoms with different types of solid state detectors. Thermoluminescent and radiophotoluminescent dosimeters were used for non-neutron dose measurements while secondary neutrons were measured with track etched detectors and bubble detectors. Measurments were performed inside phantoms representing 5- and 10-year old child and treatment of a 5 cm diameter brain tumour was simulated.

Proton irradiations were carried out at the Cyclotron Centre Bronowice IFJ PAN (Krakow, Poland) using a pencil beam scanning technique (PBS) at a gantry with a dedicated scanning nozzle (IBA Proton Therapy System, Proteus 235). Out-of-field doses measured for intensity modulated proton therapy (IMPT) were compared with 3 different photon radiotherapy techniques: 1. Intensity Modulated Radiation Therapy (IMRT), 2. Three-Dimensional Conformal Radiation Therapy (3D-CRT) and 3. Gamma Knife Surgery (GK). Experiments for IMRT and 3D-CRT were performed on a Varian Clinac 2300 linear accelerator in the Centre of Oncology (Krakow, Poland), while irradiations with GK were performed on the Leksell Gamma Knife at the University Hospital Centre (Zagreb, Croatia).

Results for IMPT showed that non-neutron doses are higher in the 5-year-old phantom compared to 10-year-old phantom due to increased proximity of organs to the target. Neutron doses are lower than non-neutron doses close to the target (factor of 4 in thyroid) while neutron doses become larger than non-neutron doses further away from the target (factor of 3-4).

Comparison of different techniques showed that proton therapy results in lower out-of-field doses compared to 3D-CRT, GK and IMRT techniques by one order of magnitude close to the brain and more than two orders of magnitude further away from the brain.

References:

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CONSENSUS PROCESS ON THE PRE-TRIAL RTQA PROCEDURES

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Radiotherapy quality assurance (RTQA) is a staple of clinical trials. Inter-institutional and inter-observer variation in the radiotherapy treatment of study participants can introduce bias and/or variations in patient outcome that could mask the investigated clinical effect. Such variations can be broadly categorised as either arising from 1) heterogeneities in delineation and planning practice across different institutions, or 2) from variations in machine output and beam modelling from center to center.

The latter source of variations is controlled by RTQA organisations via mandatory pre-trial dosimetry audits. These always include a

Beam Output Audit (BOA) performed in reference conditions; almost always these are accompanied by measurements in more complex geometries and conditions, using phantoms to mimic patients characteristics and thereby testing the capability of a center to plan, calculate and deliver one or more test treatment plans. These are referred to as Complex Dosimetry Checks (CDC).
The EORTC has adapted its requirements for BOAs and CDCs over the years to reflect changes in technologies and techniques. This work reports on a DELPHI consensus process aimed at updating the current procedures and parameters for BOAs and CDCs in EORTC clinical trials.
The process is focused on including specific checks for new technologies (particle therapy, MR-Linacs, ...) and specific parameters and tresholds for new techniques (SRS/SBRT, ...).
Acceptable parameters, procedures, thresholds and frequencies for BOAs and CDCs are being defined in the iterative DELPHI process. Final results will be presented at the ECMP 2022 congress.

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HOW TO APPROPRIATELY DETERMINE NON-TARGET DOSES IN RADIOTHERAPY?

PhD Liliana Stolarczyk[1,2]

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Even though a number of studies on non-target doses is available in the literature, estimation of out-of-field dose for an individual patient remains a challenge. EURADOS Working Group 9 (Radiation Dosimetry in Radiotherapy) since 2010 has been working to improve out-of-field dosimetry for photon and particle therapy.
In radiotherapy the main sources of non-target doses are primary beams, and secondary and scattered radiation. Secondary and scattered radiation is produced in the interactions of the primary beam with treatment nozzle and patient body and creates a low dose envelope outside the treatment field. Depending on the quality of primary radiation, scattered and secondary radiation is a mixture of scattered X-rays, secondary γ radiation, neutrons, charged particles, characteristic X-rays, bremsstrahlung radiation and residual radiation from radioactivation. For photon beams out-of-field doses depend on: field size, number of MUs, accelerator type, beam energy and treatment technique. Radiation spectrum is dominated by scattered photons, but for energies above the threshold for photo-neutron interactions secondary neutrons are created. In proton radiotherapy out-of-field doses depend on delivery method, beam modifiers and properties of proton beam. Secondary radiation field is dominated by neutrons, which together with secondary photons and scattered and secondary protons create a complicated mixed radiation field.
The most common method used for determination of non-target doses are calculations with treatment planning systems. TPS gives precise dose information only in the proximity of the target, and only in the area covered by a planning CT. Monte Carlo simulations allow for scoring different particles and calculations in the whole-body phantoms. Long computation times and lack of information needed to build a MC model of a treatment machine are the main drawbacks of this method. Analytical models may successfully describe both primary beam and secondary radiation but their accuracy is a limiting factor. Measurements can provide high quality data, but dosimetry in a mixed field of primary, secondary and scattered radiation is challenging due to dose gradients, and variable sensitivity of detectors to different radiation qualities.
Final challenge lies in the estimation of the total non-target dose including not only dose from radiotherapy (primary and secondary radiation) but also imaging and diagnostic procedures. Different components of total dose are characterised by different radiation quality, energy spectra and LET distributions. Moreover, for dosimetry of non-target doses, dosimetric quantities, which would allow to sum up doses from different radiation sources, should replace quantities typically used for radioprotection.

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QUALITY CONTROL TESTING IN RADIOLOGY: LATEST UPDATES

Richard Elek[1,2], Prodromos Kaplanis[3], Vesna Gershan[5], Virginia Tsapaki[4]

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The IAEA has a long history of providing scientific guidance on various topics. Expanded throughout its technical cooperation programmes, regional projects and other means, the Human Health Series publication series proved to be a useful source of information for medical physics community. The presentation reveals the latest effort, the 'Handbook of basic quality control tests for diagnostic radiology' (QC Handbook).
Most IAEA Member States' and every European Union Member States' regulation on medical exposures explicitly require that acceptance tests are performed before the commissioning of medical radiological equipment and thereafter performance tests are carried out on a regular basis, and after every major maintenance procedure liable to affect their performance. These are referred to as quality control or QC tests.
The IAEA Member States' representatives participating in the RER/6/028 regional project, agreed that while QC is a must to ensure the safe and effective use of diagnostic imaging modalities, the learning curve for newcomers may be steep to carry out such tests and select methods suitable to achieve the aim. In order to address this issue, the participating IAEA Member States of this project proposed to prepare a compilation of tests from the most up to date sources available. Drawing on the experience about the national status for QC tests of the Member States' delegates and the reviews by major scientific organizations such as AAPM, EFOMP and IEC, the selection of the tests was based on an approach to achieve crucial information about the technical performance of a given modality at an affordable cost in terms of instrumentation and time. Tests to be performed during acceptance and on a regular basis by the physicist and the radiographer are also included for radiography, fluoroscopy and angiography, mammography and computed tomography. The handbook describes film-screen, computed radiography and digital imaging specific tests, tests of diagnostic image displays, as well as methodology on how to perform a reject rate assessment and supervise an imaging suite in the radiology department. Each test has a structure which is easy to follow, giving a brief introduction, describing the test itself step-by-step, then the analysis and interpretation of its results and the possible corrective actions. It also provides useful insights and alternative methods where appropriate. Besides compiling the basics to initiate a quality assurance programme, the QC Handbook is complemented by spreadsheets and training videos.

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QUALITY ASSURANCE IN QMRI

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Magnetic resonance imaging (MRI) is generally used as a simple imaging device, in a way similar to X-Rays or other imaging devices in healthcare. It is however also capable of providing measurements of various parameters. One can separate the quantities measurable by MRI into two groups. On one side, there are the physical parameters, existing independently from the machine used to measure them, such as the blood flow velocity, the diffusion properties of a tissue, the perfusion rate, or even the water fat fraction of an organ. On the other hand, certain parameters are more intrinsically linked to MRI, such as the relaxation times (T1 and T2), or the number of protons forming the magnetization, all of which typically depend on the MRI itself, particularly on the magnetic field.

From a regulatory perspective, MRI scanners are Class II medical devices, but they are not considered as medical devices capable of a measurement, as would be a thermometer for example. As such, their use in clinical practice as a measuring device has had limited success in the wider clinical community, while remaining a scientific and academic endeavour.

Because of this lack of regulatory basis, it is generally accepted that measurements done on different MRI scanners, even for properties that should be fully independent from the methodology (see parameters list above) are very difficult to reproduce, thereby limiting their potential uptake within the wider clinical community. There are however many additional quality assessment procedures that can be performed, in particular using phantoms, to ensure a minimum quality for a particular scanner. These QA procedures have been typically listed in very precise documents on the Quantitative Imaging Biomarker Alliance (QIBA) website (https://qibawiki.rsna.org/index.php/Main_Page), and can be used to ensure a minimum quality needed to achieve a particular claim. These claims are generally providing a general guideline to measure in vivo a certain quality (such as e.g. the apparent diffusion coefficient) with a certain precision.

In this presentation, I will be reviewing the general aspects surround quality assurance in MRI, as well as quality control, when images are used as part of a clinical trial for example. I will also develop in more details the concepts based on which MRI can become quantitative, and its basic, intrinsic limitations. I will finish by reviewing the practical aspects to be implemented for imaging QA in trials, largely based on the existing QIBA methodology.

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FROM CONVENTIONAL TO AUTOMATED QC IN RADIOLOGY IMAGING

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Regular quality control testing of medical radiological equipment has shown to improve clinical image quality and reduce patient radiation exposure. Unfortunately, this has been largely overlooked throughout the world. As part of the quality assurance programme various tests need to be performed at certain time intervals such as annually, by-annually, monthly, or weekly tests. Annual testing alone is inadequate to detect short term fluctuations in some critical components of the imaging chain.

Remote quality control tools are used to facilitate daily or weekly testing to ensure consistency of performance between comprehensive annual evaluations. Additionally, automated quality control tools allow for more advanced analysis of image quality parameters. However, most existing efforts involve complicated and expensive test objects and infrastructures.

The IAEA has just released a remote and automated solution for radiography and mammography quality control (Human Health Series 39) using simple, inexpensive test objects (phantoms) and free software program. The phantoms enable quality control tests to be performed on a daily or weekly basis using a detectability index (d´), and the accompanying software allows for complete and automated evaluation of the principal performance characteristics of the imaging chain. The IAEA methodology provides a standardized way for testing the performance of X ray radiography and mammography machines in the everyday clinical practice even for remote sites where travel is difficult. The phantoms can be easily fabricated using material that is readily available. The software is robust and reproducible, and the implemented metrics provide the latest objective measures of image quality, making them also a valuable adjunct to traditional quality control approaches. Automated and remote testing can now be performed on units for which quality control has been lacking.

It is envisioned that much benefit can be derived from collaboration between facilities and institutions using the IAEA methodology. Such collaboration can be as simple as sharing of trouble-shooting techniques or helping with the development of clinical imaging protocols. Future steps could include establishment of user groups, both on-line and face-to-face meetings and members of these groups can provide an informal venue for the exchange of ideas and methods along with discussion of problems and solutions.

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PREPARATION AND IMPLEMENTATION OF A PROTON THERAPY SYSTEM IN SUPPORT OF FIRST IN-HUMAN FLASH CLINICAL TRIAL

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In 2014, interest in FLASH radiotherapy (FRT) was revived by research into ultra-high dose rate (UHDR) irradiations by Fauvadon et al. This work showed that UHDR irradiations have the potential for normal tissue sparring while providing comparable tumor control efficacy, as compared to conventional irradiations. In recent years, research into FLASH and UHDR has grown substantially, because of the potential for enhancing the therapeutic window through improving normal tissue sparring while preserving tumor control efficacy. In October 2020, at Cincinnati Children's Hospital and the University of Cincinnati Proton Therapy Center, the first FRT clinical trial, Feasibility Study of FLASH Radiotherapy for Treatment of Symptomatic Bone Metastases (FAST-01) [2], began accruing patients and, by November 2021, met enrollment.

Preparations for FRT clinical trials involve many technical aspects, notably but not exclusively (1) absolute dose and dose rate, (2) safety and shielding, (3) treatment planning, (4) quality assurance and (5) clinical readiness and treatment. In this presentation, the work in support of a proton therapy, transmission beam, pencil beam scanning FRT clinical trial (FAST-01) is discussed in detail. A special focus is placed on practical implementation and communicating lessons learned and knowledge gained through translational research and hands-on experience in a clinical FLASH environment. For FAST-01, the technical preparations, combined with a safety-first clinical trial design, led to the successful execution and enrollment of the first FRT clinical trial. Current and future FRT sites may find this experience generalizable to other modalities, setting, and clinical trial plans.

ORAL PRESENTATIONS

8

APPLICATION AND COMPARISON OF MACHINE LEARNING ALGORITHMS TO PREDICT VMAT GAMMA PASSING RATES

Ms Laura Medina-Bazaco[1], Mr Carlos Fernández-Leira[1], M.S.c Olivia Jordi-Ollero[1], Dr Victor Hernández[2], Dr Jordi Saez[3], M.S.c Ismael Sancho[1], M.S.c Rodolfo de Blas[1], Dr Francisco Pino[1], M.S.c Ignasi Modolell[1], M.S.c Roberto Martín-Vaello[1], M.S.c Sergio Llácer[1], M.S.c Cristina Picón[1]

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Purpose: It is compulsory to verify volumetric modulated arc therapy (VMAT) treatment plans. The demand for VMAT treatments has increased over the years and its verification is time consuming. Few studies in literature aim to predict gamma verification passing rates (GPRs) using machine learning algorithms (MLA). For this purpose it is not well established an efficiency rating among MLA. We aim to evaluate MLA for predicting GPRs and to compare performance among the classification and regression algorithms most used.
Material and methods: We measure 514 verification VMAT treatment plans using ArcCHECK system (Sun Nuclear Corporation, Melbourne). We perform 3%/2mm GPRs with a global gamma passing criteria > 90%. The predominant locations used are prostate, head and neck, lung and rectum. We develop three classification MLA and three regression MLA in order to predict GPRs. We train our algorithms using cross-validation with 75% of the plans and test them with the 25% left. We use 26 different complexity indexes as prediction variables.
We use Random Forest (RF), Neural Network (NN) and Support Vector Machine (SVM) as classification algorithms. We use ordinary least squares (OLS), Lasso and Ridge methods as regression algorithms. We evaluate classification algorithms performance with the area under the curve (AUC) and sensitivity. We evaluate regression algorithms performance with the mean absolute error (MAE) and the root mean squared error (RMSE).
Results: For classification methods, AUC and sensitivity in the test dataset are 0.75 and 0.50, 0.79 and 0.61, and 0.58 and 0.17 for RF, NN and SVM, respectively. Both RF and NN algorithms predicts accurately even if NN outperforms.
For regression methods, the three models predict accurately and can be used indistinctly. MAE and RMSE in the test dataset are 2.17% and 3.23%, 2.13% and 3.21%, and 2.14% and 3.24% for OLS, Lasso and Ridge, respectively. The most important features selected to predict GPRs are mean tongue and groove index, modulation complexity score, modulation total index and edge metric.
Conclusion: In spite of good performance for RF and NN algorithms, discreet results in sensibility are determinant for clinical applicability. MLA with sensibilities below 100% cannot ensure clinical workflows to be able to detect all plans with GPRs <90%.
Results in regression MLA allow not performing Archeck verification for treatment plans with predicted 3%/2mm GPRs above 94%, with total reliability on detecting all plans with GPRs <90%.

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BACKSIDE IRRADIATION OF UV-A TO GAFCHROMIC FILMS FOR CORRECTING NON-UNIFORMITY ERROR

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To correct the non-uniformity and uncertainty of Gafchromic films, the films are irradiated with ultraviolet (UV) A rays. There is a difference in the UV protection strength of Gafchromic films. A concern exists about the effects of the UV irradiation intensity and heat generation of the UV irradiation equipment. We thus irradiated with UV rays the back sides of the films to assess if back-side irradiation is possible.
Gafchromic XR-QA2 and RTQA2 were used in this study. The UV-A rays were simultaneously irradiated on the front and back sides of each film for 12 h. The yellow layer of each film was scanned and imaged. The average pixel values ± standard deviations (SDs) were compared. In the statistical analysis, a paired t-test was performed to compare the active-layer densities engendered by the UV-A rays. The mean pixel value ± SD for XR-QA2 on the front and back sides were 130.776±0.812 and 81.015±1.128, respectively. On the other hand, the mean pixel values ± SD for RTQA2 on the front and back sides were 62.299±1.077 and 133.761±1.365, respectively. The statistical results of the paired t-test were significantly different ($p < 0.01$) for both films.
Based on the relationship between the sensitivity of the active layer to UV-A rays and the strength of UV protection on the surface, we concluded that back-side irradiation is recommended for XR-QA2, and front-side irradiation is recommended for RTQA2.

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BIOLOGICAL EFFECTIVENESS OF STEREOTACTIC RADIOTHERAPY INCREASES WITH FRACTIONATION IN HYPOXIC TUMORS

Mr Filippo Schiavo[1,2], Emely Kjellsson Lindblom[1,2], Pierre Barsoum[3], Alexandru Dasu[4], Iuliana Toma-Dasu[1,2]

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Purpose: Tumor hypoxia hinders the success of radiotherapy because of the increased resistance to radiation. There are other factors that also influence the response to a treatment, such as the fractionation scheme and the heterogeneity in the dose distribution. It is hence expected that the response of a hypoxic tumor depends on the radiotherapy technique used and the dose distributions involved. This work aims at comparing proton radiotherapy and Gamma Knife (GK) radiosurgery with respect to the control of hypoxic brain metastases.
Material and methods: A previously developed three-dimensional in silico model of a tumor was used to simulate single and multifractionated iso-effective treatments for hypoxic brain metastases. The tumors, consisted of a well-oxygenated peripheral layer surrounding a hypoxic core. GK and proton therapy with 5 iso-effective fractionation schemes were compared. The reference for iso-effectiveness was a single fraction dose of 20 Gy to a well-oxygenated cell population, assuming hypofractionation in the comparison between plans. One GK plan with a biologically equivalent dose (BED) of 20 Gy at the 50% isodose surrounding the target was made and two proton plans: one aiming at a homogeneous iso-effective dose of 20 Gy and one highly heterogeneous, GK-like. The effects of potential permanent vascular collapse in the tumor were simulated and the tumor control probability (TCP) determined for the different irradiation scenarios.
Results: For a hypoxic tumor (diameter 0.9 cm) with a core hypoxic fraction (HF) of 42%, the TCP for the GK radiosurgery plan was 66%. While the homogeneous proton treatment plan failed to control the

tumor, the heterogeneous one achieved a TCP=97%. For fractionated treatments the TCP for the GK increased progressively up to >93% for the 5-fraction scheme, although the first fraction was assumed to raise the HF in the tumor core to 68% as a result of permanent vascular collapse, while the heterogeneous proton plans improved further the control rate. This effect is explained by the fact that the BED for hypoxic cells increases with the number of fractions: for an iso-effective dose of 60 Gy for oxic cells, the BED for the most hypoxic cells (α/β=30 Gy) increased from 33.3 GyBED to 43.5 GyBED.
Conclusions: Hypofractionated GK treatment plans show potential in controlling hypoxic tumors even in the presence of induced permanent vessel collapse. Proton plans would fail to lead to the same positive results unless high heterogeneity in the dose like the GK profile is intentionally employed.

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DOSE OPTIMIZATION IN PERCUTANEUS ENDOVASCULAR EMBOLIZATION OF MALE VARICOCELE

Valentina Ravaglia[1], Carlo Cecchelli[2], Simona Farnedi[1], Domenico Palmarini[2], Nicola Pannacci[2], Nicoletta Scrittori[1], Giovanna Venturi[1]

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Purpose: Aim of the study was to optimize the fluoroscopy guided procedures for percutaneus endovascular embolization of varicocele in order to reduce the absorbed dose to the gonads of the patients, which are mainly adolescent or young males.
Material and methods: From February 2020 to January 2022 a total of 105 patients were treated in our radiology department for varicocele embolization. All procedures were performed by three experienced interventional radiologists using a Philips Allura Xper FD20 angiography system (Philips) and 4 ml of sclerosing agent in combination with coils.
The first group of 45 patients were treated with "low" fluoroscopy protocol (15 fps and a filtration of 0.4 mm Cu + 1 mm Al) while 35 patients were treated with a modified "ultra low" protocol (7.5 fps and a filtration of 0.9 mm Cu + 1 mm Al).
Median values for fluoroscopy time (min), reference air kerma (mGy) and DAP (Dose Area Product, mGy•cm2) were calculated and, to evaluate a statistical difference between the 2 groups, a p-value ANOVA one-way analysis was performed.
Results: The median fluoroscopy time, reference air kerma and DAP for the group 1 were respectively 287 s, 25.6 mGy and 8.5 mGy•cm2 while for group 2 were respectively 287 s, 11.1 mGy and 2.4 mGy•cm2. The reduction in terms of reference air kerma and DAP were respectively of 57% and 72%.
The distribution of fluoroscopy time values between the 2 groups were not significantly different, while reference air kerma and total DAP values resulted significantly lower for patients of the second group, treated with the modified "ultra low" protocol (p-values of the ANOVA one-way analysis < 0.001).
Conclusions: The use of the modified "ultra low" protocol significantly reduced the dose both in terms of reference air kerma and DAP respect to the original protocol, without significant loss of image quality.

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IMPACT OF DAILY ANATOMICAL CHANGES AND INTRAFRACTION MOTION ON DOSE DISTRIBUTION DURING ULTRA-HYPOFRACTIONATED PROSTATE CANCER RADIOTHERAPY

Dr Francesca di Franco[1,2], Dr PierreMarie Pialat[1], Dr Thomas Baudier[1,2], Dr Pascal Pommier[1], Dr, PhD David Sarrut[1,2], Dr, PhD Marie Claude Biston[1,2]

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Purpose: To quantitatively characterize the dosimetric effect of daily anatomical variations and intrafraction prostate motion during ultra-hypofractionated prostate cancer radiotherapy treatments.
Material and methods: Fifteen prostate cancer patients (75 treatment sessions) treated in our institution were included in this study. The prescription dose was 36.25Gy to 100% of the Clinical-Target-Volume (CTV) prostate in 5 fractions, delivered using volumetric modulated arc therapy. Daily Cone Beam CT (CBCT) imaging was performed for pre-treatment positioning, whereas intrafraction motion monitoring was done using Clarity transperineal ultrasound (TP-US) probe (Elekta AB, Stockholm). The CBCT images were thereafter registered and deformed to the planning CT (pCT) to generate synthetic CT (syCT) using ADMIRE V3.37 (Elekta AB, Stockholm) for performing dose accumulation. The daily dose distribution taking into account the anatomy of the day was calculated and target coverage and dose to the rectum and bladder were assessed. Then on each syCT, the voxel shifting method was used to move the dose maps every second of treatment, according to the movements retrieved by the TP-US. The resulting shifted dose maps were accumulated and the dosimetric parameters were evaluated in function of time.
Results: CTV coverage dropped from (99.6±0.3)% in pCT to (94.0±4.1)% in the accumulated CT (aCT). The bladder was found to be smaller in 76% of all fractions on syCT versus pCT. This resulted in an increase in bladder D40% from (7.0±5.9)Gy in the pCT, to (9.7±5.2)Gy in the aCT. The bladder D5cc was (36.0±1.1)Gy for the pCT versus (33.6±3.7)Gy for the aCT. Conversely, in 50.3% of all fractions rectum volume was smaller than in the pCT and the rectal D50% was (12.8±3.8)Gy in the pCT versus (12.4±3.9)Gy in the aCT. The rectum D1cc was (35.3±0.7)Gy versus (34.0±2.3)Gy for the pCT and aCT, respectively. Introducing prostate's intrafraction motion, the dosimetric variations increased with time. After 10 minutes treatment, an increase in bladder D40% and D5cc to (10.2±5.7)Gy and (36.2±4.3)Gy was respectively observed. Conversely, rectum D50% and D1cc remained approximatively unchanged to (12.6±3.8) Gy and (34.3±2.8)Gy, respectively. On average, a reduction in CTV coverage to (91.4±6.7)% was observed.
Conclusions: We showed that CTV coverage was both impacted by fluctuations in bladder and rectum's volume and by intrafraction motion. Hence this is of importance, in the context of stereotactic radiotherapy, to have a strict protocol for bladder and rectal fillings and a monitoring tool to control prostate's intrafraction movements.

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ASSESSMENT OF TLD RING DOSIMETER HP(0.07) ACCURACY FOR A RANGE OF EMERGING THERAPEUTIC AND PET RADIONUCLIDES - EGSNRC MONTE CARLO SIMULATION AND EXPERIMENTAL VALIDATION

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Purpose: The extremity exposure of Nuclear Medicine workers is routinely monitored by Lithium fluoride (LiF)-based Thermoluminescent Dosimetry (TLD) ring dosimeters. Their response is dependent on the type and energy of the incident radiation, the detector effective thickness and the irradiation geometry. Previous studies have found a significant variation in the accuracy of TLDs depending on the monitored isotope. In particular, a sub-optimal response of some TLDs to positron emitters such as ^{18}F was noted. A correlation between the filter and detector thickness, and the response to beta particles has also been reported, indicating the need for isotope-dependant TLD configurations. However, in many centres a single TLD type is used to monitor extremity exposure for all isotopes; encompassing a range of energy spectra and radiation types. This study aims to quantify the accuracy of commercially-available TLDs for a selection of existing and emerging clinically-relevant radionuclides.
Materials and methods: The EGSnrc Monte Carlo (MC) simulation software was used to estimate the dose to (1) fingers and (2) ring dosimeter TLDs, in contact with unshielded and shielded syringes containing ^{99}mTc, ^{64}Cu, ^{18}F, ^{11}C, ^{13}N, ^{15}O, ^{68}Ga, ^{82}Rb, ^{89}Zr, ^{90}Y, ^{177}Lu and ^{131}I, respectively. Doses received at various distances from the syringe were also modelled, with dose rates reported in terms of skin equivalent (Hp(0.07)) doses. The energy spectra for each isotope at various locations in the simulations were also generated. Experimental measurements with ^{18}F, ^{68}Ga, ^{131}I and ^{99}mTc were performed for validation purposes.
Results: In the anatomical model, Hp(0.07) simulated dose rates across all isotopes ranged from 0.09 to 54.75 µGy/MBq.hr at 30 cm from an unshielded syringe. The beta energy spectra for each isotope was simulated in air, outside the syringe wall, and in the skin layer. The mean beta energy incident on the Hp(0.07) layer in skin, after traversing the syringe wall, ranged from 0.05 to 0.65 MeV, while the maximum energy ranged from 0.07 to 2.79 MeV. At this location, six of the eleven radionuclides assessed had a mean energy <200 keV and five had a maximum energy >800 keV, which may be outside the operational energy ranges of some TLDs.
Conclusion: The spectra obtained in this study confirm a range of energies are reaching the Hp(0.07) layer, resulting in significant skin doses for higher energy isotopes. The TLD beta spectra and assessment of the accuracy of the TLDs will also be presented.

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DOSIMETRIC STUDY IN PAEDIATRIC PATIENTS WITH CONGENITAL HEART DISEASES EXPOSED TO X-RAYS AND SUBMITTED TO DIAGNOSTIC AND INTERVENTIONAL PROCEDURES

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Purpose: Paediatric patients with congenital heart diseases need to undergo a series of diagnostic and interventional procedures using X-rays from the early stages of their lives.[1] The elevated survival rate of surgical correction, prolongs their lives with good quality of life, but several complications and sequela remain, that need to be diagnosed using advanced image technology, such as CT scans, and to be treated with catheterization techniques. Due to their complexity, these diagnostic and therapeutic methods involve a high number of accurate radiologic images, sometimes repetitive acquisitions, resulting in cumulative long periods of exposure to X-rays and protracted exposures to ionising radiation (IR).
Materials and methods: This study aims to evaluate the radiation doses received by patients during the execution of diagnostic and intervention cardiology procedures and to estimate the biological risk of IR exposure in a group of children submitted to cardiac catheterisation at a Single Portuguese Reference Centre of Congenital Heart Diseases, using measurements Monte Carlo (MC) methods with age-specific computational sequences, based on paediatric anthropomorphic phantoms (CIRS ATOM 705) experimental tests.
Results: The simulation of the Cath lab was successfully implemented using MCNPX as well as the voxelization of the CIRS ATOM 705 phantom. The X-ray source was simulated and the results compared with the results obtained from real measurements.
Conclusion: Future work will include dose estimation in the different organs of paediatric patients, and afterwards correlate it with radiobiological results that allow inferring a relationship between radiation exposure and chromosomal damage, or other injury.
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PATTERN-OF-PRACTISE, MULTI-CENTRE BENCHMARKS AND CREDENTIALING WORKFLOW FOR CONTOURING, TREATMENT PLANNING AND DELIVERY OF STEREOTACTIC ARRHYTHMIA RADIOABLATION FROM THE STOPSTORM.EU CONSORTIUM

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Purpose: The purpose of the "Standardised Treatment and Outcome Platform for Stereotactic Therapy Of Re-entrant ventricular tachycardia by a Multidisciplinary" (STOPSTORM) consortium is to generate a treatment registry and to optimise and harmonise STereotactic Arrhythmia Radioablation (STAR) for ventricular tachycardia (VT) across Europe.
Material and methods: The EU-Horizon-2020 STOPSTORM (STOPSTORM.eu; Grant: 945119) project comprises 31 clinical/research institutes and is divided into nine work-packages centred around a comprehensive STAR registry. We present the first results of the quality-assurance work-package with respect to: (1) Credentialing, audit and review workflows for STAR within the STOPSTORM.eu registry; (2) STAR patterns-of-practise in Europe based on comprehensive surveys; (3) Benchmark results for contouring and treatment planning both based on three example STAR cases; and (4) Quality-assurance levels within the consortium based on treatment unit audits and dose measurements.

Results: The STOPSTORM treatment registry has obtained primary ethics approval in December 2021. (1) Treatment quality guidelines are based on international recommendations for Stereotactic Body Radiotherapy (SBRT) and STAR. A credentialing and audit committee reviews all cases using newly developed software for joined electrophysiology-radiotherapy data presentation. (2) Catheter ablation for VT (20/24 centres ≥ 20/year) and SBRT (13/22 centres > 200/year) experience is present in the consortium, whereas 16 centres already performed 84 STAR treatments until May 2021. In most centres, single fraction doses of 25 Gy are applied while prescription methods, dose inhomogeneity and planning techniques vary greatly. (3) The contouring benchmark showed high accuracy with non-cardiac structures showing significant better agreement than cardiac substructures (DICE range: 0.57-0.92 vs. 0.16-0.84, $p < 0.001$). For treatment planning 75% of the centres used Intensity Modulated Arc Therapy with 6 MeV flatting filer free beams while 73% preferred critical organ sparing over achieving high target coverage demonstrating significant diversity in current STAR approaches (planning target volume mean dose 22.7-31.4 Gy vs. left anterior descending artery max dose 10.1-33.8 Gy). (4). 40% of the centres successfully performed patient-specific plan verifications for STAR so far, but with various methods and evaluation criteria.
Conclusions: STAR for refractory VT necessitates early standardisation due to its novelty and complexity. STOPSTORM was established for this purpose and a comprehensive quality-assurance work-package will ensure high-quality data for pooled clinical results. As a first step, current STAR practice in Europe was captured showing significant variance in clinical practise.

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IMPLEMENTATION AND DOSIMETRY OF AN OPTIMISED SPATIALLY FRACTIONATED RADIATION THERAPY TECHNIQUE AT A CLINICAL MEDICAL ACCELERATOR

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Purpose: Normal tissue tolerances continue to be the main limitation in radiotherapy. Finding novel approaches leading to a reduction in toxicity would allow the escalation of the tumor dose, resulting in an improvement in cure rate. This is especially needed in the case of radio-resistant tumors, such as high-grade gliomas. Spatially fractionated radiotherapy (SFRT) is a strategy with proven potential to overcome this main limitation of radiotherapy (1). However, SFRT, with techniques such as GRID or lattice therapy, has been mainly used with palliative intent. This is due to the limitations related to its current implementation where significant lateral scattering leads to a reduction in the peak-to-valley dose ratios (PVDR), an important indicator for normal tissue sparing. Another drawback is the need for comparatively large beam sizes (around one square centimetre) in order to retain an acceptable dose rate. Here we propose a new optimised approach for the use of SFRT in a clinical environment: GRID therapy with small beams at the 6XFFF TrueBeam® system (VARIAN, Palo Alto, USA) (2). This new implementation has the potential to move from palliative to curative treatments for some radioresistant tumors.
Materials and methods: Suitable optimized collimators were manufactured by means of electrical discharge machining and 3D metal printing in order to compare the performance of both methods. Experimental dosimetry was carried out with high resolution detectors.
Results: A successful implementation was achieved. Very small beamlet sizes (≤ 2 mm) at the isocenter were achieved with excellent dose rates (7 Gy/min). The beam widths are 5 times narrower than conventional GRID therapy, therefore a significant increase in normal tissue tolerances is expected thanks to dose-volume effects. A PVDR as high as 10 was also obtained in certain configurations.
Conclusions: This is the first technical implementation of an optimized GRID therapy technique at a medical LINAC. To the best of our knowledge, this new avenue has not yet been explored in any center, and it might dramatically reduce the upfront investment in SFRT, thus easing its spread. A series of radiobiological experiments are ongoing. If confirmed, the gain in tissue sparing/recovery will help in the elimination of the main barrier in RT treatments: the tolerance doses of normal tissue.
Disclosure: This study has been funded by VARIAN, a Siemens Healthineers Company.
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PROTON MINIBEAM RADIATION THERAPY FOR TREATING BRAIN METASTASES: A TREATMENT PLAN EVALUATION

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Purpose: Proton minibeam radiation therapy (pMBRT) is a novel radiotherapy approach (Prezado, 2013) that has demonstrated a significant reduction in normal tissue toxicity and equivalent or superior tumour control, compared to standard proton therapy (Prezado, 2018). The treatment of brain metastasis situated close to critical structures seems to be a suitable candidate to benefit from this technique. In this study, the potential of pMBRT was evaluated by comparison with stereotactic radiosurgery (SRS) treatments, a technique currently used in clinics for this type of indication (Specht, 2016).
Materials and methods: Two clinical cases, initially treated with SRS, were selected for this study. pMBRT treatments consisted of one fraction and one or two fields, as proposed for phase I/II clinical trials. The use of different centre-to-centre distances between minibeams to obtain different levels of heterogeneity at the target was evaluated. Three criteria were used to compare SRS and pMBRT treatments: (i) the tumour coverage, (ii) the mean dose to organs-at-risk (OARs), and (iii) the possible adverse effects to the normal brain by computing the normalized total dose at 2 Gy per fraction (NTD2.0). The different fractionation schemes were considered for these evaluations. Dose calculations were computed by means of Monte Carlo simulations.
Results: pMBRT can provide a similar or superior tumour coverage as compared to SRS. This approach also reduces the biologically effective dose (BED) to critical structures by 44-100%. The dose to the entire body also decreases by up to 48%. Additionally, pMBRT

cases studied meet the dose constraints regarding the maximum dose tolerated by the healthy brain.
Conclusions: pMBRT seems to be a promising alternative for the treatment of brain metastases. This approach may widen the therapeutic ratio, as compared to conventional techniques, by reducing the dose to critical structures and maintaining the tumour control. pMBRT treatments can be effectively delivered in one single fraction and 1-2 fields, reducing the possible uncertainties between sessions and the total treatment duration. These results can guide the design of the first pMBRT clinical trials.

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LUNG NODULE VOLUMETRY AND MORPHOLOGY IN CHEST CT: EFFECT OF DEEP LEARNING VERSUS ITERATIVE RECONSTRUCTION AT DIFFERENT DOSE LEVELS

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Purpose: Unlike iterative reconstruction (IR), deep learning image reconstruction (DLIR) has shown to preserve the FBP-like image texture at reduced dose levels. It is unknown whether volume measurements of lung nodules on DLIR images are comparable with measurements on IR images. In addition, the nodule's morphology may change depending on the level of dose reduction used. This study assessed the value of DLIR compared to IR at different dose levels, in terms of lung nodule volumetry and morphology perception in chest CT.
Material and methods: An anthropomorphic chest phantom containing 6 spherical, 6 lobulated and 6 spiculated 3D printed solid nodules (volume range 28-392 mm^3), was scanned at 0.2, 0.4, 0.8, 1.5, 3 and 6 mGy. Images were 1.25mm reconstructed with ASIR-V 60% and three levels of TrueFidelity (Low, Medium, High).
The volumes of 432 nodules (18 nodules × 6 doses × 4 reconstructions) were measured by five experienced radiologists. In addition, the nodule's IQ was scored on a five-point scale (1=poor, 5=excellent). Readers were blinded for dose and reconstruction algorithm.
Mean %-error in volume measurements was assessed for all reconstructions and dose levels, with respect to the ground truth (high dose scan, 11 mGy). A smaller absolute %-error indicates a higher accuracy. Percent IQ score frequency was calculated per reconstruction algorithm and dose level. Subsequently, volume measurements and IQ score were stratified per nodule type.
Results: In general, mean %-errors decreased with increasing dose. On average, errors were significantly lower with TrueFidelity (3.6/3.4/3.0% for Low/Medium/High) than with ASIR-V (4.1%), for all dose levels (p=0.001). With increasing DLIR level, errors decreased for the lower dose range (0.2-0.8 mGy), while for higher doses (1.5-6 mGy) values were comparable.
Overall, IQ was higher for TrueFidelity compared to ASIR-V, with 94% of DLIR cases having an IQ≥3, versus 84% for IR. When stratifying per dose level, the percent frequency of IQ≥3 for IR/DLIR algorithms was: 26%/70% (0.2 mGy), 80%/94% (0.4 mGy), 96%/100% (0.8 mGy), 100%/100%(1.5 mGy), 100%/99% (3.6 mGy), 100%/100% (6.4 mGy).
Conclusions: In chest CT, volume measurements with TrueFidelity showed a significantly higher accuracy compared to ASIR-V, for all dose levels and all nodule types. Lung nodule morphology perception performs equally or better with TrueFidelity compared to ASIR-V, for all nodule types. At very low dose levels (0.2-0.8 mGy) DLIR outperforms IR, while at higher dose levels (≥1.5 mGy), DLIR and IR are comparable in terms of nodule perception.

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DETERMINATION OF FUNCTIONAL PERFUSED LUNG SUBVOLUMES FROM DUAL-ENERGY CT AND PET IMAGING FOR FUNCTIONAL LUNG AVOIDANCE RADIOTHERAPY

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Purpose: Functional lung avoidance (FLA) radiotherapy treatment aims to spare regions of functional lung. Normal lung perfusion is a characteristic of functional lung and refers to blood flow through alveolar capillaries, a highly radiation sensitive tissue in lung. In our institution, lung perfusion is assessed from positron emission tomography (PET). Dual energy CT (DECT) may be an alternative to PET, providing higher resolution, shorter acquisition time and better patient access. This study aims to determine the correlation between DECT and PET perfusion imaging in the context of FLA radiotherapy.
Material and methods: We assessed Ga-68-macroaggregated albumin PET/CT and DECT images acquired at baseline of consecutive patients with non-small cell lung cancer undergoing definitive radiotherapy enrolled in the prospective HI-FIVE clinical trial (ID: NCT03569072). DECT perfusion imaging was measured from pulmonary blood volume (PBV) maps generated by a commercial software (Syngo.via, Siemens, Germany) with its lowest (PBVsyngo:R=1) and highest (PBVsyngo:R10) noise filter value (R) and from an in-house two-material decomposition (TMD) method used with a median filter (PBVtmd:r) of variable radius (r). The resulting transformation of deformable image registration (b-spline, Plastimatch) performed on DECT images to the CT component of the PET/CT was applied to PBV maps before resampling to the PET resolution. The voxelwise Spearman correlation coefficient [rs(X,Y)] between imaging technique X and Y was calculated.
Results: Baseline DECT and PET/CT were available in 17 of 19 patients. Surrogate maps generated by the commercial software and the TMD method were strongly correlated [rs(PBVsyngo: R=1, PBVtmd: r=1) = 0.96±0.01 and rs(PBVsyngo: R=10, PBVtmd: r=8) = 0.93±0.02]. PET perfusion was moderately correlated with the two DECT methods [rs(PET,PBVtmd: r=18) = 0.57±0.17 and rs(PET,PBVsyngo: R=10) = 0.51±0.14]. Differences affecting the correlation were observed in the posterior region [rs(PET,PBVtmd: r=18) = 0.40±0.25/0.68±0.13 in the POST/ANT region]. All results were statistically significant.
Conclusions: DECT perfusion imaging was moderately correlated with PET perfusion. Main differences were located posteriorly due to blurring in PBV maps and gravitational deposition in PET.

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ULTIMATE VALIDATION OF THE STATISTICAL METHOD FOR LOW CONTRAST DETECTABILITY (SM) IN ANGIOGRAPHY FOR STATIONARY AND MOVING DETAILS: COMPARISON WITH HUMAN OBSERVER TASKS

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Low contrast detectability assessment in fluoroscopic images is generally achieved watching a movie of a test object containing low contrast details and choosing a subjective threshold contrast (Cth); the viewing frame rate should be the same of the acquisition frame rate. The direct evaluation of the contrast detail curve during a QA session is time consuming and the subjective score is affected by a relevant error. In addition, commercial phantoms have a well-known template, affecting human observers score.

An objective and quantitative evaluation of the contrast detail curve can be achieved applying the statistical analysis over uniform frames of a fluoroscopy run. Considering several identical regions of interest (ROI) placed on a uniform background, each with a mean pixel value μ, the standard deviation of these means can be used to predict the detectability of an insert, identical in size to the considered ROI. The Cth, characterised by 95% confidence level, is given by Cth (x)=3.29 σμ(x), where σμ is the standard deviation of all means from ROIs of the same size.

The commercial CDRAD phantom has been exposed using an Angiography device in fluoroscopy acquisition mode. During the acquisition the CDRAD phantom was both stationary and in motion on the patient table. A blank slab of PMMA has been acquired with the same set-up.

Images of the CDRAD phantom have been segmented and cropped over each detail using the Hough transform. From each detail, 200 stacks of 10 frames each have been built both for stationary and moving test objects. Furthermore, the same segmentation has been applied over the blank images. Human observer experiments were conducted in the form of two alternative force choices experiments (2AFC); the viewing frame rate was set equal to the acquisition one. The percent correct (PC) for each observer was calculated as the number of correct responses divided by the number of trials.

Low contrast threshold have been calculated with statistical method algorithm in Pixel Value units and the converted in Contrast unit. The temporal resolution correction has been applied to these data to take into account the capability of the human observer to integrate and visually merge noise over a fixed period of time. The averaging process was performed on groups of frames that correspond to number of frame visible in the same position during 200 ms.

Applying temporal resolution to SM results match with 2AFC human observer experiment.

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QUALITY CONTROL IN ULTRASONOGRAPHY

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Purpose: The need for ultrasound quality control (US QC) testing has been discussed in the past few years (1).

A complete US QC program was established in the Radiodiagnostic service of our facility in 2019 and is carried out annually. It consists of some tests designed to detect degradation in image quality before it affects clinical diagnose.

In this work, results from measurements performed on 29 transducers corresponding to 10 ultrasound systems have been analyzed. The limitations of our phantom are also discussed.

Material and methods: The Multipurpose N-365 urethane phantom (Kyoto Kagaku) was used to perform the tests. Acoustic velocity and attenuation coefficient (25ºC) of this phantom are 1432 m/s and 0.59 dB/cm/MHz, respectively. It contains inserts of different sizes and echogenicity for evaluation of different image quality parameters.

The QC tests were performed on 15 linear and 14 convex transducers corresponding to 10 Toshiba Aplio and Xario ultrasound systems. The tests performed were: uniformity, dead zone, penetration depth, focal zone, horizontal and vertical distance accuracy, axial and lateral resolution, anechoic object imaging and low contrast resolution.

The tolerances considered were established following the AAPM Ultrasound Task Group No.1 recommendations. Values of frequency, gain, dynamic range, focus and field depth that optimized image quality had been set in the implementation.

Results: 8 convex and 13 linear transducers out of a total of 29 met tolerances for all the tests. Superficial artifacts were encountered for 6 probes during the uniformity check. Dead zone, depth of penetration and focal zone met tolerances for all the transducers. The low contrast resolution test also had excellent results.

Vertical and horizontal distance measurement accuracy met tolerances for 26 and 29 probes, respectively.

Lateral resolution required specific tolerances for this type of phantom. Only one transducer did not pass the axial resolution test. 3 transducers showed distortion in the anechoic objects visualization test.

Conclusions: As it is discussed in the literature, a phantom with acoustic velocity different from 1540 m/s is not recommended to check distance measurement accuracies, nor to measure the system spatial resolution. However, it can be used to check consistency of results over time.

In addition, using a QC program it is possible to detect malfunctions in US probes, having a deep impact in patient care.

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GENERATIVE ADVERSARIAL NETWORKS BASED GROUND GLASS OPACITIES (GGOS) SYNTHETIC

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Background and objective: The robustness of deep learning (DL)-based computer aided diagnosis (CAD) systems for the automated detection of pulmonary nodules in low-dose CT scans strongly relies on the availability of a large amount of curated and annotated data. Even when this holds true, the unbalance problem will exist. For example, GGOs will be harder to be recognized by the algorithm, because of their lower prevalence compared to part solid and solid nodules. DL algorithms such as GANs can be utilized to generate synthetic samples, thus increasing the original datasets and improve the CAD detection accuracy. However, the quality of the generated samples should be evaluated both qualitatively (visual inspection) as well as quantitively to prove a clinical relevance.

We proposed and evaluated a novel structure for generating GGOs through Super resolution GANs.

Methods: 216 CT images (340 GGO nodules) from The Lung Image Database Consortium and Image Database Resource Initiative (LIDC-IDRI) database were used. An optimized super resolution GANs built on retrieving information from the whole image and the GGO region was developed. The generated samples were evaluated asking four trained radiologist/pulmonologist to perform a visual Turing test (VTT) and by comparing quantitative imaging features (radiomics) between real and synthetic nodules in four grades confidently fake, leaning fake, leaning real, and confidently real.
Results: The results of the VTT. More than one-third (37.3%) of the synthetic GGOs were classified as 'Real', of which 15.7% were classified as 'Confidently Real. A total of 58/93 radiomic features had no significant difference ($P > 0.05$) between synthetic and real GGOs. The ROC curves constructed based on the results of radiologists and radiomics a similar classification performance between radiologists (AUC = 0.68) and radiomics (AUC = 0.66).
Conclusion: In this study, we used GANs to generate synthetic GGOs in low-dose CT images. The above studies show that the generated nodules closely match real samples, both visually and quantitatively.

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A NOVEL AND SUCCESSFUL APPROACH TO ATTRACTING STUDENTS TO MEDICAL PHYSICS AND RADIATION PROTECTION UNIVERSITY PROGRAMMES

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Purpose: In Malta the Medical Physics and Radiation Protection professions faced an acute shortage of entrants to the professions owing to the low popularity of two year masters programmes and the irregular number of physics/engineering graduates. Under such conditions of uncertainty the two professions would not only fail to grow but inevitably decline, leaving patients, carers and comforters, research participants, and hospital staff and visitors without the medical physics and radiation protection services required by EU directive 2013/59/EURATOM. A formula needed to be found to: (a) address the paradox of having to reduce the masters programme to one year at a time when the knowledge-skills-competences required for modern medical physics and radiation protection practice are expanding rapidly owing to the increasing complexity of medical device technology (b) ensure that the potential stock of entrants to the profession would be independent of erratic student numbers in other departments and faculties.
Material and methods: A literature review and survey of Medical Physics undergraduate and postgraduate Masters in Medical Physics was carried out. Best practices were identified and adopted.
Results: The best way forward was to opt for an undergraduate inter-faculty programme that combined physics, medical physics and radiation protection. This ensured that the resulting degree would satisfy the undergraduate requirements for Medical Physicists, Medical Physics Experts and Radiation Protection Experts as stipulated by the European Guidelines on the Medical Physics Expert, EFOMP and IAEA guidelines for Medical Physics and the ENETRAP, IRPA and HERCA guidelines for Radiation Protection Experts. The resulting four year programme consists of 5 parallel strands namely physics/mathematics/statistics, medical-physics/radiation-protection, basic-medical-sciences, research and hospital placements. Those opting for a Medical Physics career can then follow with a Masters in Medical Physics. Because of the solid undergraduate background the Masters in Medical Physics now includes all specialties of Medical Physics plus machine learning and pattern recognition.
Conclusions: This innovative curricular experiment has been a great success. The inter-faculty nature of the programme (where students share lectures with both physics students from the Faculty of Science and healthcare students of the Faculty of Health Sciences) together with the element of clinical practice have been found to be the most appealing features.

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CONSIDERATIONS ON A CASUAL WORKFORCE FOR RADIATION ONCOLOGY MEDICAL PHYSICS

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Purpose: Medical Physics is typically one of the smaller workforce groups in oncology. While lack of staff may not immediately impact on activities, it will have a medium and long term detrimental effect and cannot easily be addressed as a lot of medical physics work is highly specialised and requires extensive training. We report on a project to create a casual workforce in a large cancer hospital that would be able to support regular staff during absences or in times of high workload.
Methods: Candidates for the scheme were recent graduates of a medical physics Masters course accredited by the Australasian College for Physical Scientists and Engineers in Medicine (ACPSEM). Completion of such a course is also a pre-requisite for applying for one of the sought after registrar positions for the three year clinical training program leading to certification by ACPSEM. The first intake of six persons occurred in 2019 based on quality of applications and a short interview probing motivation and communication skills. Casuals were formally appointed for one year and (paid) practical training in linear accelerator quality assurance provided on 2 to 4 weekends which coincided with monthly quality assurance activities. Training elements are:
1. Linac familiarisation
2. Linac mechanical checks
3. Practical dosimetry
4. Linac beam profile checks
5. Linac MV imaging
6. Linac kV imaging
7. Motion management systems

Results: Peter MacCallum Cancer Centre operates 16 linear accelerators on 5 campuses and offers a large number of treatment approaches. A total of 0.6 EFT (equivalent full time) allowance was made for the casual workforce giving opportunity to provide approximately 20 hours of support per week. Casuals were required (and supported) to obtain a radiation license. Several casuals had already some practical experience prior to commencing and were able to quickly perform routine tasks under limited supervision. All measurements need to be countersigned by a certified physicist. The program grew to also include CT scanner and kV treatment unit quality assurance but clinical measurements, plan checks and brachytherapy are considered not suitable for the casual workforce.
Conclusion: The casuals' project proved to be a success allowing to back-fill some positions in a 'cascade' fashion and made out of hours work safer as at least two staff members are present. It also provided the casual workers with practical experience and personal contacts that helped one to commence a PhD and two to obtain full training positions.

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CLINICAL FEASIBILITY OF MR-ONLY-BASED SYNTHETIC CT GENERATION FOR ONLINE ADAPTIVE RADIOTHERAPY USING A HYBRID MR-LINAC

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Purpose: A hybrid magnetic resonance linear accelerator (MRL) can acquire MR scans with high soft-tissue contrast for online adaptive radiotherapy (oART). To obtain electron densities needed for oART dose calculations, a computed tomography (CT) is often deformably registered to a daily MR scan. However, the deformed CT (dCT) is not always accurate and may require manual corrections. Our aim was to evaluate an MR-only-based synthetic CT (sCT) generation approach as an alternative to the dCT-based oART in abdominal region.

Material and methods: This study retrospectively included 53 patients treated primarily for abdominal tumors on a 0.35T MRL (ViewRay®). Simulation MR-CT pairs from 43 patients were used for training and validation of a prototype neural-network-based sCT algorithm for the abdominal region. The algorithm developed by Spectronic Medical® only requires an MRL-acquired MR scan as the input to produce an sCT. For clinical testing, sCT volumes were generated from 3–6 daily MR scans of the remaining 10 patients (12 RT courses), and the dCT-based plans were re-calculated on sCT with unchanged settings.

We compared the sCT and dCT-based approaches regarding image quality and dosimetric agreement. For the image quality, we examined the Hounsfield unit (HU) agreement using mean error (ME) and mean absolute error (MAE). For the dosimetry, we considered the dose difference relative to the dCT-based calculation at clinically relevant dose-volume-histogram (DVH) points for 14 planning target volumes (PTV) and multiple organs-at-risk (OAR). The DVH points were taken from an accumulated dose of each RT course obtained through non-rigid registrations using elastix in 3DSlicer.

Results: For 63 dCT-sCT pairs, the mean and one standard deviation of ME and MAE were 8±13 HU and 56±7 HU, respectively, with the largest deviations observed in bony regions. For PTVs, the dose differences were 0.6±1.0%, 0.6±0.9%, and 0.6±0.8% at D2%, D50%, and D98%, respectively, and all the values were within -0.5%–2.6%. For OARs, the dose differences of all the evaluated DVH points were within -4.4%–5.7% (mean: 0.4±1.3%).

Conclusions: The presented MRI-only-based approach for oART at MRL using sCT is a promising alternative to the existing clinical practice. The HU-value agreement was on par with previously reported sCT results and the mean dose differences were within 1%, which indicate that the sCT generation algorithm is clinically feasible. The presented approach may remove the time-consuming image-registration corrections from the oART workflow, and thus, has the potential to reduce overall treatment time and patient discomfort.

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VISUAL PERCEPTION MODEL OBSERVER METHODS FOR LOW CONTRAST DETECTABILITY IN DIGITAL ANGIOGRAPHY

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The aim of this work is to study the practicability of spatio-temporal generalized model observer methods for protocol optimization in interventional radiography. The goal is to design mathematical model observer methods, based on psychophysical studies, to predict consistently human performances so as to have reliable results applicable to set detectability scores of radiographic protocols involving dynamic images.

Two model observers were taken under examination: a Channelized Hotelling Observer (CHO) with 24 spatio-temporal Gabor channels and a Non-Prewhitening Model Observer (NPWE) with two different implementations of the spatio-temporal contrast sensitivity function. Two series of images, both stationary and in motion, were acquired in fluoroscopic mode using a CDRAD phantom for signal present images and an homogenous slab of PMMA for signal-absent ones. In order to acquire statistically significant samples, every acquisition was taken for a total time of 200s and the respective images were cropped and segmented through the Hough transform, taking advantage of the radiopaque grid on the CDRAD.

These processed images were used to build three series of two alternative force choice (2AFC) experiments and submitted to three human observers in order to set a goal on detectability: the first task involved the detection of both stationary and sinusoidal moving signals, the second task was built for sinusoidal moving signal recognition compared to the stationary one and the third task was designed for linear moving signal detection.

Verification and validation of the models were made as follows, for different acquisition parameters and motion conditions: a first set of images was used for model tuning and subsequently the verified models were validated through a second set of images.

The CHO appears to be very sensitive to acquisition and motion parameters for every task; however this feature limits the range of parameters for which the model can be applied. The results for the NPWE highlight a specific insensitivity to motion conditions when dealing with images containing signal for the same amount of time, thus confirming the position shift invariance of this model. However, with the appropriate tuning factors, both CHO and NPWE models show good agreement with the human observer performances (RMSE <10%) for all tasks.

The tuning phase emerges as a crucial step in building models for dynamic images and the so found agreement underlines the good capability of these models in simulating human performances, allowing to consider them as a useful and worthwhile tool in clinical protocol optimization.

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INTEGRITY OF PERSONAL RADIATION PROTECTIVE EQUIPMENT (PRPE): A 4-YEAR LONGITUDINAL FOLLOW-UP STUDY

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Purpose: Personal radiation protective equipment (PRPE) such as lead aprons, vests, skirts and thyroid shields minimize radiation

exposure of operators using X-ray systems. However, PRPE might be prone to cracks and tears in the attenuating layer of the garments which results in inadequate radiation protection and increased operator dose. This study aimed to investigate the prevalence, qualification and quantification of PRPE integrity during a longitudinal follow-up.

Material and methods: All PRPE of a large, general hospital was yearly evaluated in the period 2018-2021. The equipment was inspected on a tele-operated X-ray table and cracks and tears were qualified and quantified using an X-ray opaque ruler. Rejection criteria of Lambert and McKeon were applied to accept or reject further use of the PRPE. In brief, all pieces, except for thyroid shields, with a total defect area larger than 670mm^2 are rejected. Individual tears were subject to an extra rejection criterion of 15mm^2. For thyroid shields, the rejection criterion was set to 11mm^2.

Results: A total of 1011 PRPE were evaluated. Overall, 47.3% of PRPE showed tears of which 31% exceeded the rejection criteria. More specifically, in 2018, 2019, 2020 and 2021, respectively, 17.6%, 17.3%, 22.3% and 17.3% were rejected. Remarkably, of 287 newly registered PRPE, 7.0% showed tears in the first year of use of which 88.2% needed to be rejected. Brands that allowed repair were systematically higher in rejection rate compared to non-repairable brands. The 4-year average rejection rate of repairable brands versus non-repairable was respectively 24.5% versus 5%. Of the 766 controls performed on repairable pieces, 31.7% led to repairs at least once. Reparation was confirmed the consecutive year by the health and safety department and each repaired piece was labeled with a repair note. Almost 50% (48.1%) of pieces that were at least repaired once, were again rejected the consecutive year.

Conclusions: PRPE are prone to artefacts, resulting in a reduced protection. A systematic quality control of PRPE, revealed that up to 50% of PRPE showed tears and cracks. The latter resulted in 31% rejections. Newly purchased PRPE are not guaranteed to remain free of cracks and tears in the first year of use. This study emphasizes the necessity of regular X-ray based integrity analysis of PRPE to ensure adequate radioprotection of operators using X-ray systems.

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DESIGN AND COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF A NOVEL ANCHORING SYSTEM IN THE INFERIOR VENA CAVA FOR CENTRAL VENOUS PRESSURE MEASUREMENT – A NEW APPROACH TO HEART FAILURE MONITORING

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Purpose: In recent years, treatment of Heart Failure (HF) patients has proved to benefit from implantation of pressure sensors in the pulmonary artery (PA). While longitudinal measurement of PA pressure profoundly improves a clinician's ability to manage HF, the full potential of central venous pressure (CVP) as a clinical tool has yet to be unlocked. CVP serves as a surrogate for the right atrial pressure, and could potentially predict a wider range of HF conditions. However, it is unclear if current sensor anchoring methods, designed for the PA, are suitable to hold pressure sensors safely in the Inferior Vena Cava (IVC). The purpose of this study was to design an anchoring system for accurate apposition into the IVC, and evaluate whether it is a potential site for CVP measurement.

Material and methods: A location inferior to the renal veins was selected as an optimal site based on CT scan analysis. Three anchor designs, a 10-strut anchor, and 5-struts with and without loops, were tested on a custom-made silicone bench model of Vena Cava targeting the infra-renal IVC. The model was connected to a pulsatile pump system and a heated water bath that constituted an in-vitro simulation unit. Delivery of the IVC implant was accomplished using a preloaded introducer and a dilator as a push rod to deploy the device at the target area. The anchors were subjected to manual compression tests to evaluate their stability against dislodgement. Computational Fluid Dynamics (CFD) analysis was completed to characterize blood flow in the anchor's environment using pressure-based transient solver and mesh convergence. Any potential recirculation zones or disturbances in the blood caused by the struts were identified.

Results: We demonstrated successful anchorage and deployment of the 10-strut anchor in the Vena Cava model. The 10-strut anchor remained stable during several compression attempts as compared to the other two 5-strut anchor designs. It also provided the maximum number of contact points with the vessel in a circular fashion, and was less susceptible to movement or dislodgement during compression tests. Furthermore, the CFD simulation provided a hemodynamic analysis of the optimum 10-strut anchor design.

Conclusion: The 10-strut anchor design is potentially a good fit for implantation into an animal model. The ability to place a sensor technology in the vena cava provides a less-invasive approach as compared to PA implants. The procedural time with this technology and approach could be potentially shorter with fewer complications.

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DNA DAMAGE AFTER INTERNAL EX VIVO IRRADIATION OF BLOOD WITH α-PARTICLES AS A FUNCTION OF TIME AND ABSORBED DOSE

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Purpose: There is a growing number of treatments with α-particles in nuclear medicine. Since radiopharmaceuticals, such as the α-emitter [^{223}Ra]RaCl$_2$, are administered by intravenous injection, the blood of the patients is also irradiated during therapy, leading to detectable DNA damage in peripheral blood mononuclear cells (PBMCs). To date, there are only limited data on the time course of α-particle-induced DNA damage and correlations with the absorbed dose to the blood. Therefore, in this study, we investigated DNA double-strand break (DSB) damage in PBMCs of volunteers as a function of time and the absorbed dose to the blood following internal ex vivo irradiation with [^{223}Ra]RaCl$_2$.

Material and methods: Blood samples of ten healthy volunteers split into several aliquots. One aliquot per volunteer served as non-irradiated control while three aliquots where irradiated by adding [^{223}Ra]RaCl$_2$ solution resulting in three pre-determined absorbed doses to the blood (25 mGy, 50 mGy and 100 mGy) after 1 h incubation at 37°C. Part of each aliquot was retained to determine the activity concentration for dose calculation. To quantify DSB damage, the biomarker γ-H2AX was used. PBMCs were isolated, divided in three parts and either fixed directly (d-samples) using ethanol or after 4 h or 24 h. The fixed PBMCs were subjected to DSB staining with γ-H2AX antibodies. Subsequently, γ-H2AX-positive tracks (α-tracks) were counted in 500 cell nuclei.

Results: The number of α-tracks was significantly increased compared to baseline in all irradiated samples. In the d-samples, the number of α-tracks increased linearly with the absorbed dose to the blood. After 4 h and 24 h, the α-track frequency decreased significantly compared to the corresponding d-samples. The time-dependent decrease in DNA damage could be modelled by an exponential function assuming a repair rate R and a fraction of non-repairable damage Q. The R-values were (0.24±0.05) h-1 for 25 mGy, (0.16±0.04) h-1 for 50 mGy and (0.13±0.02) h-1 for 100 mGy, suggesting faster repair at lower absorbed doses. The fractions Q (0.09±0.03, 0.12±0.03, 0.06±0.03) were similar for the absorbed doses investigated.
Conclusions: The time- and dose-dependency of track-like DSB damage induced by internal irradiation with the α-emitter [^{223}Ra] $RaCl_2$ was investigated ex vivo under defined conditions and modelled using appropriate fit functions. The obtained results suggest that induction and repair of the DSB damage depend on the absorbed dose to the blood. Further studies are needed to confirm these findings in vivo for therapies with α-emitting radionuclides.

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THE USE OF DOSE RATE DEPENDENCIES AS A THEORETICAL DISCRIMINATION CRITERIA IN RADIOBIOLOGICAL MODELS

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Purpose: Different biological assays may be used to infer cell repair kinetics after radiation-induced damage (e.g., time-resolved comet assay, γ-H2AX, etc.). Whereas alkaline comet assays exhibit a large spread of DNA fragments in tail (most of them produced by single strand breaks), γ-H2AX data represent a mixture of the repair kinetics and the kinetics of the assay itself. Therefore, it is difficult to directly measure the cell repair by only using one of these assays. To overcome this problem, we propose the use of survival dose-rate effects as an indirect method to gain knowledge about cell damage and repair dynamics and, in particular, the theoretical use of these effects to improve the fitting of radiobiological models. Since the repair speed is encoded in the dose-rate survival data and may be dose-rate dependent, interpreting repair kinetics from different assays readouts requires the use of model-based data analysis involving dynamic radiobiological models.
Material and methods: The Multi-Hit Repair (MHR) model is used as an example of radiobiological model. This model was chosen because of its dynamical nature and its ability to reproduce diverse biological experimental data such as clonogenic - and comet assay readouts. On the other hand, after a review of the available literature data, different fractionation/dose-rate -related qualitative effects common to most of the cell lines were found and they are used as theoretical discriminators to discard totally unrealistic dynamics of the model.
Results: The theoretical dose-rate discriminators are proven as a powerful tool which can discard a great number of model parameter sets (99%) leading to unrealistic repair kinetics. Furthermore, the remaining model parameters distributions show an improvement in the model fitting by reducing the search range for two of the three parameters which were still uncalibrated. However, more data are still needed to fully understand the repair dynamics.
Conclusions: The results validate dose-rate experiments as an alternative method to gain knowledge about cell repair kinetics and to improve the fitting of radiobiological models. Moreover, qualitative common dose-rate dependencies can be used as theoretical discriminators when experimental data are not available. This approach is proven as a powerful tool which helps to improve the model fitting by discarding theoretical unrealistic repair dynamics.

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LUNG SHUNT FRACTION ESTIMATION FOR Y-90 BOTH AT THERAPEUTIC AND DIAGNOSTIC ACTIVITY LEVELS: A PHANTOM STUDY

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Purpose: The aim of this study was to assess the accuracy of lung shunt fraction (LSF) estimation in both high activity Y-90 posttreatment scans, and pretreatment scans with the isotope activity of ~100 MBq, using different imaging techniques: PET/CT, Bremsstrahlung SPECT/CT as well as planar imaging, by means of phantom experiments.
Materials and methods: Anthropomorphic phantom containing liver and lungs was filled with Y-90 chloride to simulate an LSF of 9.8%. Nine measurement sessions including PET/CT, SPECT/CT and planar images were acquired at activities ranging from 1618 MBq down to 43 MBq. For PET imaging a clinical protocol with 30 min/bed position was used. For SPECT we tested three protocols with different energy window settings: 0-280 keV (W1), 100-200 keV (W2), and 100-200 keV divided into 4 narrower emission windows (W3) to provide more accurate CT based attenuation correction. Time per projection was 30 sec. High-energy collimators were used. For each series of measurements the static images were acquired twice using energy windows of W1 and W2, with acquisition time of 5 min. Considering the relatively long acquisition time on PET/CT scanner, a correction for the natural background was applied by performing a series of PET measurements with the phantom containing no activity. Additionally, for PET imaging an LSF of 0% (LSFsimulated) was simulated by delineating an extra region without activity within the phantom.
Results: For high activity in the phantom, PET reconstructions slightly underestimated the LSF; absolute difference was <1.5pp (percent point). For activity <100 MBq, the LSF was overestimated. The background correction allowed to obtain better LSF results. Along with the decrease in activity, the LSFsimulated was increased (up to 4% at 100 MBq, while for activities ≥500 MBq it was less than 1%). Bremsstrahlung SPECT overestimated the LSF regardless of the energy window setting in the whole range of activity. The W2 energy window yielded the best results (absolute difference <3pp for activity ≥100 MBq). Planar images greatly overestimated the LSF (up to 16pp for W1 and 18pp for W2).
Conclusions: PET/CT may accurately estimate the LSF in a Y-90 posttreatment procedure. However, for this imaging technique, low activities of ~100 MBq seem to provide unreliable estimations. Since the main source of the LSF overestimation in Bremsstrahlung

SPECT/CT imaging is scatter radiation, a reconstruction algorithm for its correction is required.
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DEVELOPMENT AND VALIDATION OF MONTE CARLO SIMULATIONS FOR DOSIMETRY MEASUREMENTS IN A CLINICAL C-ARM CONE BEAM COMPUTED TOMOGRAPHY (CBCT) IMAGING SYSTEM

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Purpose: Patient dosimetry estimation approaches for cone beam computed tomography (CBCT) acquisitions are still under development. Due to the wide-beam geometry of a CBCT system, dosimetry and scatter radiation contributions are commonly underestimated. In addition, the incomplete nature of the C-arm rotation during acquisition leads to an inhomogeneous dose distribution, not present in the case of fully rotational conventional computed tomography (CT). A number of experimental and modelling approaches have been suggested in the literature for in-phantom and patient dosimetry for wide-beam CBCT. However, there is not yet a clear consensus on a preferred method to adopt in the case of diagnostic radiology, particularly for interventional radiology systems. The purpose of this study was to develop an interventional radiology C-arm CBCT dosimetry model using Monte Carlo (MC) simulations and to experimentally validate the model. A further aim was to examine the effects of off-centred positioning and subject size on dosimetry estimations.
Materials and methods: Three 320 mm diameter body CTDI phantoms were used to generate the long scatter geometry (cumulative length of 450 mm) for imaging in a Siemens Artis Q C-arm CBCT interventional radiology system. TOPAS MC, a Monte Carlo GEANT4 simulation toolkit, was used to model the radiation transport in the three phantom configuration and generate a dosimetry map of the CBCT field of view. A standard 100 mm pencil ionization chamber (Radcal Corporation, US) and a 0.6 cc Farmer–type ionization chamber (10X5-0.6CT, Radcal Corporation) were used to measure the phantom dose distributions from clinical abdominal protocols. The positional distance of the phantom arrangement from iso-centre was varied in both the lateral and horizontal planes while the dosimetric effects of varying subject size was also investigated using 160 mm diameter head CTDI phantoms.
Results: The dose distribution within the long scatter geometry will be presented and compared with experimental dosimetry data for each ion chamber at each location to estimate the effects of scatter, rotation and positioning on in-phantom and patient dosimetry. The experimental phantom data will be used to validate the MC modelling, with further models being used to demonstrate the effects of off-centring and subject size.
Conclusions: This study will provide dose distribution maps within a long subject scatter geometry through MC modelling of an interventional C-arm CBCT system. The model will be demonstrated to account for subject positioning and size variations, towards the development of a patient specific dosimetry method.

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EFOMP POLICY STATEMENT 17: THE ROLE AND COMPETENCES OF MEDICAL PHYSICISTS AND MEDICAL PHYSICS EXPERTS IN THE DIFFERENT STAGES OF A MEDICAL DEVICE LIFE CYCLE

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Purpose: The life cycle management of medical equipment is described as well as the procedures involved. These procedures are performed by healthcare teams with a collaboration of many professionals. Our workgroup is focusing on the role of the Medical Physicist and Medical Physics Expert – here collectively referred to as Medical Physics Professional (MPP) in these teams. The policy statement describes the role and competences of MPPs in every stage of a medical device life cycle. If MPPs are an integral part of these healthcare teams, this can lead to better health care quality and reduced costs.
Material and methods: Possessing a scientific educational background with advanced technical skills, MPPs are well suited to play a leading role within each stage of a medical device life cycle. The various stages of the life cycle include establishment of requirements with use-case assessment, investment planning, procurement of equipment, acceptance testing especially regarding safety and physical behaviour, quality management, effective and safe use and maintenance, user training, interfacing with IT systems, and safe decommissioning and removal of the equipment. In a responsibility assignment matrix, the participation of MPPs by various roles in completing tasks or deliverables for a project or business process is described.
Results: Nowadays, only few MPPs are strongly involved in the overall life cycle management of the equipment they are using regularly. To obtain a balanced life cycle management of medical equipment in a healthcare institution, the governance must be defined, and procedures must be standardised. MPPs need to play a prominent role in all processes described.
Conclusions: All EFOMP National Member Organisations should encourage the healthcare institutions and the individual MPPs to closely work together in the life cycle management. MPPs have the competencies and knowledge to play an important role in most stages of a medical device life cycle. Nevertheless, the actual needs for the involvement of MPPs may vary from institution to institution and will be dependent on the processes already in place. Institutions are invited to review their processes and adapt the whole system as described, or elements thereof. By evaluation of the outcome, the need of involvement of MPPs in the different stages of a medical device life cycle can thus be determined, giving MPPs a stronger position in healthcare organisations throughout Europe.

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EUTEMPE ATELIER: AN EXAMPLE OF TEACHING BEYOND THE GOOD OLD PRESENTATION

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Purpose: For many of us, the good old PowerPoint presentation is the default choice as a vehicle to transfer knowledge. Even though this can be a powerful teaching method, we should consider that it is not always the most effective strategy. Many alternative approaches are available that could be more appropriate than the standard lecture format. The purpose of this work is to discuss alternative methods

and the different conditions for which they might be appropriate. As an example of a teaching event in which different strategies are used, we will use the EUTEMPE Atelier, a preconference session at ECMP 2022, as a use-case.

Methods: When choosing a teaching method, it is crucial to consider the learning objectives of the event. Different objectives require different teaching methods. When you want participants to only gain knowledge, a well-prepared lecture is an excellent method. But when it comes to, for example, applying concepts, participants should be given the opportunity to actively practice.

The objective of the EUTEMPE Atelier is to not only teach knowledge, but also job-related problem-solving and presenting skills. In order to reach that objective the participants will be immersed in real-life problem situations. They will work in groups on three different cases, related to dosimetry, equipment, and leadership. Three renown experts in these fields will speak about their experiences with similar problems they have encountered in their careers, and will coach the participants while they work on the cases. At the end of the day, the groups will present their solutions, and receive feedback by the experts.

Results: Actual learning outcomes are always influenced by a lot of different factors. Choosing the right teaching method, or the right blend of methods, is one of these factors.

In the EUTEMPE Atelier we combine different didactical methods - action learning, case-based learning, and group learning; to prepare participants for an often-unruly reality that requires both hard and soft skills. The expected results of the Atelier are that participants will learn how to apply deep theoretical knowledge to complex problem situations, and how to convince decision makers at a higher level.

Conclusions: As educators of medical physicists, we need to be aware of other, more appropriate, possibilities beyond giving PowerPoint presentations, to prepare them for real-life problem situations. We should expand our educational tool bag and use different methods to enhance the learning processes of the participants and improve the learning outcomes.

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THE MANAGEMENT OF OCCUPATIONAL DOSES IN INTERVENTIONAL RADIOLOGY BASED IN ELECTRONIC DOSIMETERS TOGETHER WITH PATIENT DOSE INFORMATION

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Purpose: The management of radiation doses in interventional practices is still a challenge for many medical physics departments. High radiation doses may be required during these procedures and interventionalists must participate in an important number of procedures, exposed to the scatter radiation. In this work we show the approach developed in a university hospital to manage the occupational dose of operators in interventional practices to seek individually, for the specific situations/moments with the highest doses that may require optimisation.

Methods: Wearing electronic dosimeters on the chest over the apron (personal use), Hp(10) is recorded every second and sent to hubs located at interventional labs, creating and redirecting occupational dose reports to a central database. The patient radiation dose structured report is also sent to the central database, where occupational dose records are structured in similar way, at radiation event and procedure level. Patient and occupational dose are served in web applications to the final users. Results from 5441 procedures recorded during 2021 are shown.

Results: Eight interventional laboratories and 29 interventional professionals (interventionalists, radiographers and nurses) are being monitored with the help of this system. The system shows differences in a factor of two in cumulative Hp(10)/procedure over the leaded apron between different operators of the same department (68 vs 32 uSv/procedure). Transjugular intrahepatic portosystemic shunt revealed as the procedure with the highest average Hp(10), 240 uSv/procedure, versus other like hepatic chemoembolization 46 uSv/procedure, or nephrostomies 53 uSv/procedure. In interventional cardiology, transcatheter aortic valve implantations recorded the highest average occupational dose (over the apron) with 36 uSv/procedure. This analysis can be performed individually for each interventionalist, even each procedure can be analysed in a time-line, seeking for the most complicated moments (radiation events) with the highest occupational doses.

Conclusions: Thanks to this approach, medical physicists and interventionalists can deepen the optimisation, analysing those procedures or situations which contribute to occupational doses the most.

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PATIENT-SPECIFIC DOSE CONSTRAINS TO MINIMIZE RADIOTHERAPY-INDUCED LUNG CANCER RISK FOR BREAST CANCER

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Purpose: External beam Radiotherapy (RT) post conserving surgery is the "Gold Standard" for early stage of Breast Cancer (BC). This approach may introduce an excess risk for RT-induced lung cancer. To minimize side effects some constraints are respected during the treatment planning, but these do not include long-term effects such as secondary cancers. This study proposes a new model that allows the patient-specific dose constraints calculation to minimize RT-induced lung cancer risk.

Materials and methods: Using the Schneider Mechanistic Model, RT-induced lung cancer risk has been estimated for 288 patients (aged between 30 and 70 years) treated using Standard Fractioned Three-Dimensional Conformal Radiation Therapy (SF 3D-CRT) at Humanitas - Istituto Clinico Catanese (H-ICC) (Misterbianco, Italy). Organ Equivalent Dose (OED), Excess Absolute Risk (EAR), Lifetime Attributable Risk (LAR), Relative Risk (RR) values were calculated starting from ipsilateral lung differential DVH (available directly from the TPS). Statistical parameters required by Schneider's model were taken from different sources: H-ICC, Istituto Nazionale di Statistica (ISTAT), and Integrated Cancer Registry CT-ME-EN. Some simulations have been performed on the whole statistical sample imposing an attained patient's age (age_a) equal to 75 Y and varying the age of the patient at the time of exposure (age_e) from 30 and 70 years in 5-year steps.

Results: A linear relation (R^2=0.96) was also found between OED and V_4 (% lung volume absorbing a dose of 4 Gy. As a result of these, it is possible to obtain the LAR value as a function of V_4 and agee:

LAR = (A × exp(-age_e/B) + C) × (M + N × V_d)
This model is named V_d Simplified Model (VSM). To minimize the difference between LAR from Schneider's model and LAR from VSM parameters were optimized minimizing MSE obtaining: A=-0.300 [(1/10000 P) Gy-1], B=-11.387 [Y], C=147.601 [Gy-1], M=0.830 [(1/10000 P) Gy-1], N =0.069 [Y]. The percentage differences (Δ%) between LAR_Schneider and LAR_VSM values is < 5%. Explicit V_4 from the VSM equation and imposing the LAR value equal to the LIR percentages (100, 90, 80, 70, 60 and 70%), new patient-specific constraints were determined. According to the VSM for 1.5 < RR < 2 must be 15% < V_4 < 42%.
Conclusions: The results obtained allow the introduction of new patient-specific dose constraints to minimize RT-induced lung cancer risk for BC already in the planning phase.

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PROOF-OF-PRINCIPLE OF WIDMAPP, A NEW APPROACH TO INTERNAL RADIATION DOSIMETRY FOR RADIONUCLIDE THERAPY

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Purpose: A systematic measurement of the internal activity distribution in patients undergoing radionuclide therapy would enable treatment improvements and individualization of the activity to be administered. A treatment personalization can increase the local control, while sparing healthy tissues and lowering toxicity. Accurate Internal Radiation Dosimetry (IRD) is a challenging task, since the dose absorbed to tissues depends on several interconnected key factors, among which are radiopharmaceutical uptake and excretion largely fluctuating from patient to patient.
A new approach for individual radioagent biokinetics determination with the Wearable Individual Dose Monitoring Apparatus (WIDMApp) has been proposed [Morganti S et al, Med Phys 2021 10.1002/mp.15311]. The WIDMApp system is conceived as a wearable multi-channel detector system for in-vivo radiation detection, and a data analysis tool to reconstruct the activity distribution and its evolution over time in different organs.
Material and methods: An experimental proof-of-principle of WIDMApp was realized using a NEMA phantom. A first prototype of the WIDMApp detecting element was developed based on a plastic scintillating crystal and Silicon photomultiplier technology. It was used to detect gamma radiation emitted from radionuclides with different decay times: 18F, 99mTc and 64Cu. Solution of these radionuclides with 54, 53 and 28 MBq respectively were injected in three spheres of the NEMA phantom to mimic organs with different time-activity trends - i.e. different radioagent biokinetics. The WIDMApp sensor was placed in three positions on the phantom surface, and used to measure the time evolution of the counts due to the gamma emitted by the three radionuclides. Data was collected over four days with a frequency of 24 minutes at each measurement point. The decay times of the three sources were estimated by fitting the data and compared with the proper radionuclide decay constants.
Results: The WIDMApp system resulted effective in deconvolving the cumulative detected signal into contributions from three different emitting volumes. The high frequent data sampling, spamming over a time interval longer than the radionuclide decay time constants, allowed for the determination of the activity temporal evolution in each sphere.
Conclusions: The proof-of-principle of WIDMApp showed that reconstruction of the individual biokinetics using small portable detectors is in principle possible. Taking advantage of the data sampling more frequent than conventional biokinetics studies, the WIDMApp system can be an effective tool for the time-activity trend determination in lesion and organs at risk of toxicity, fully characterizing the accumulation, the uptake and the retention.

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SKIN DOSIMETRY MODEL FOR CT ACQUISITIONS

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Introduction: Skin is the first organ that is exposed to X-ray during a CT scan and it can receive a relatively high radiation dose in CT procedures with repeated exposure of the same skin area such as interventional or perfusion CT. The aim of this study is to provide a skin dose model based on CT acquisition parameters to allow dose follow-up for this organ at risk.
Materials and methods: A virtual cylindrical phantom was generated (32cm,L=20cm,pixel size=0.5mm2) in DICOM format. The phantom was used as 3D geometrical model for Monte Carlo (MC) simulations with ImpactMC (Advanced Breast-CT). The impact of acquisition parameters including tube voltage (70,80,100,120, and 140 kVp), bow-tie filter (medium filter, large filter), and position in the gantry on skin dose were investigated with the MC simulations. The first layer at the surface of the phantom was considered as the skin (thickness 0.5mm2). The dose values were normalized to CTDIvol (D_CTDI). In addition, the model was validated with experimental TLD measurements and MC simulations on the humanoid Rando Alderson (RA) phantom for the large filter at 120kVp and 80-mm collimation.
Results: Results show an increase in the skin dose for decreasing distance to the isocenter. For distances smaller than 120mm, four curves were fitted to the data based on high tube voltage (HV) at 100,120, and 140kVp, low tube voltage (LV) at 70 and 80kVp), medium filter (MF), and large (LF) with the equation D_CTDI=A*x(mm)2+B*x(mm)+C;
HV-MF:A=-4.71E-05, B=-92.95E-05, C=2.09
LV-MF:A=6.92E-05, B=-240E-05, C=2.59 H
HV-LF:A=-3.96E-05, B=62.58E-05, C=1.80
LV-LF:A=-4.75E-05, B=25.49E-05, C=1.96
For distances larger than 120mm, the curves for the various kVp selections differ marginally, and one fitting formula is sufficient (A=3.74E-05,B=-0.02,C=2.79) to estimate skin dose for all combinations with an average error of 4.3% between this estimation and estimations of the exact equations.
Additionally, the skin dose values of RA phantom were in good agreement with our model at 120kVp and LF. The average deviation between the experimental TLD measurement on the RA phantom and the MC simulations of this phantom was 9%.
Conclusion: A model was developed to estimate skin dose as a function of filter type, tube voltage, and skin-isocenter distance in CT imaging. Such a model has the potential to enable the implementation of a systematic skin dose assessment and registration in clinical CT imaging. Additionally, it can estimate skin

dose prior to the CT scan based on localizer scan in combination with selected acquisition parameters.

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TARGET MOTION TRACKING IN FREE-BREATHING LUNG MR-GUIDED SBRT

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Purpose: Patients show more treatment compliance during free breathing treatment (FBT), taking generally less time respect to breath hold treatment (BHT) delivery technique. This study quantify the gross tumor volume (GTV) motion in the upper lung during a stereobody radiotherapy (SBRT) in a Magnetic Resonance (MR)-LINAC system and support the patient specific treatment technology's pre-selection, by measuring the GTV centroid position on MRI cine.

Methods and materials: Five lung tumour patients have been retrospectively enrolled in this study, after their MRI-guided FBT SBRT with the ViewRay MRIDIAN system. During the simulation and all the treatment fractions, sagittal cine 0.35T MRI allows real-time CTV movement tracking. A total of 23 cine MRI have been exported from the ViewRay treatment planning system and a home-made MATLAB script has been employed to measure the centroid position of the GTV contour on all the cine frames. The motion of the target is evaluated by measuring the standard deviation of the GTV centroid position on a single fraction. The standard deviations of the different fractions of a single patient have been then compared with the one measured on the simulation cine MRI. Moreover, the position of 8 points on the GTV delineation and their relative motion on four diagonals have been calculated to determine the shape and dimension of the target, verifying the stability and accuracy of the tracking algorithm. Homolateral lung and GTV volume have been also considered to further evaluate possible correlation with GTV movement.

Results: Standard deviation of the GTV position varies from 0.34 cm to 0.50 cm in the antero-posterior direction, and 0.27 cm to 0.55 cm in the cranio-caudal direction. GTV motion during the treatment have been always in agreement with the one measured during the simulation. The relative motion of the points on the GTV's contour shows an almost similar movement between the 8 points and the centroid. Motion measurements are not affected by Tracking algorithm. No correlations have been observed between GTV motion and lung and GTV volumes.

Conclusions: GTV contour centroid shows a standard deviation of less than 0.55 cm in both directions during the breathing phase. Simulation MRI allows to select FBT lung patients that can be treated with conventional LINAC when GTV contour centroid shows a smaller standard deviation. Future studies will investigate the maximum acceptable motion for the choice of a FBT instead of a BHI MRI-guided radiotherapy.

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GEOMETRIC AND DOSIMETRIC ANALYSIS OF AUTOMATIC CONTOURING USING THE EPTN CONTOURING ATLAS FOR CT- AND MR-BASED CONTOURING IN NEURO-ONCOLOGY

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Purpose: The use of Artificial Intelligence (AI) in radiotherapy is increasing rapidly over the last couple of years. Atlas and deep-learning based contouring are two well-known methods for automatic segmentation of organs-at-risk (OARs). In neuro-oncology, CT- and MR-imaging is used for delineation of OARs. In this study, we performed a geometric and dosimetric analysis of automatic segmentation derived using CT- and MR-models in neurological patients.

Material and methods: We created atlas-based models (Embrace, Mirada Medical) on CT- and MR-images for 26 OARs according the EPTN contouring atlas for CT- and MR-based contouring in neuro-oncology. Models were based on 10, 20 and 30 patients: CT_10, CT_20, CT_30 and MR_10, MR_20, MR_30 respectively. An independent set of 20 patients was used to measure geometrical accuracy by calculating the volumetric Dice similarity coefficient (vDSC), surface DSC (sDSC), and mean slice-wise Hausdorff distance (MSHD). Manual contours delineated on registered CT and MR-images were used as ground truth. Dose differences (ΔD's) were quantified using dose-volume histogram (DVH)-parameters according to clinical protocol (e.g. Dmean and D0.03cc) and the absolute average was calculated. Grouped dosimetric data were tested for statistical significance using Wilcoxon signed-rank tests.

Results: Geometrical analysis showed the best result for increasing atlas size (_30 models). Geometric results were better for CT-based than MRI-based atlases for 15 out of 26 OARs. Brain showed best agreement with manual contours for vDSC (CT_30: 0.98±0.01), the right cochlea for sDSC (CT_30:0.90±0.11) and MSHD (CT_30:0.13±0.04cm). For the _30 atlases, left cornea showed worst agreement for vDSC (MRI_30:0.02±0.03) and sDSC (MRI_30:0.07±0.07), the posterior cerebellum for MSHD (CT_30:0.99±0.44cm).

Dose difference were below 1Gy for respectively 19 (CT_30) and 15 (MR_30) out of 26 OARs. ΔD was on average lower for CT_30 (0.87±1.57Gy) than MR_30 (1.06±1.41Gy). Highest ΔD was found for the left optic nerve D0.03cc (CT_30:-6.44±8.75Gy), lowest ΔD for the brainstem D0.03cc (MR_30:-0.03±2.44Gy). Significant dose differences were found for respectively 9 (CT_30) and 12 (MR_30) OARs. Clinical relevance of these dose differences is further investigated.

Conclusions: Automatic generated contours should be evaluated both from geometry and dosimetry perspective. To assess the impact of contour variations, dose differences were evaluated and found below 1Gy for most OARs. Distance-to-tumor (e.g. PTV) analysis will further show to which extent the location of delineation inaccuracies relative to the PTV have a dosimetric impact and hence clinical relevance. Currently we are also evaluating the results of CT- and MR-based deep-learning segmentation in the same patient group.

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A NEW FORMULA FOR CONVERTING DOSE-AREA PRODUCT TO EFFECTIVE DOSE IN DENTAL CONE-BEAM COMPUTED TOMOGRAPHY

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Purpose: Although dose-area product (DAP) is the most commonly used dose index in dental cone-beam computed tomography (CBCT), its applicability is limited due to its non-trivial relation to effective dose (E). The purpose of this study was to determine a dedicated conversion formula between DAP and E for dental CBCT, which incorporates X-ray beam energy as well as geometric factors.

Material and methods: CBCT exposures of an adult phantom were simulated using PCXMC 2.0 (STUK, Finland). Six fields of view (FOV) were included, corresponding to the most common FOVs found in literature. FOV sizes ranged from Ø5x5cm to Ø15x15cm. The FOVs were positioned according to typical dental examinations. For FOVs with a height ≤6cm, upper and lower jaw positions were used. In addition, for the Ø5x5cm FOV, anterior and molar positions were used.
Six tube voltages were simulated, ranging from 70 kV to 120 kV. Eight combinations of Al and Cu filtration were used for each tube voltage. Finally, four source-isocentre distances were used, from 35 cm to 65 cm. Using all possible permutations of the aforementioned parameters, 1920 protocols were simulated. Effective dose and DAP for each simulated scan were recorded.
E/DAP was plotted against various features related to beam energy and beam geometry to identify and linearize the principal components. Finally, multiple linear regression was performed using Scikit-learn for Python using E/DAP as dependent variable and the principal components as independent variables.
Results: A two-component model using half-value layer (HVL, mmAl) and FOV volume (cm^3) was selected, with an R^2 of 0.975. An additional correction factor was added to compensate for anterior vs. posterior positioning; this correction only applies to the Ø5x5 cm FOV. The resulting model allowed for a conversion between DAP and effective dose with an average error of 3.1%.
Conclusions: The new formula allows for a straightforward, yet accurate, estimation of the effective dose for dental CBCT based on DAP. Further fine-tuning of the model could be achieved by incorporating, for example, bowtie filtration and off-axis beam geometries.

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Y-90 PET/CT AND SPECT/CT ANTHROPOMORPHIC PHANTOM IMAGING. QUALITATIVE AND QUANTITATIVE ASSESSMENT OF VISIBILITY OF COLD AND HOT LIVER TUMOURS

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Purpose: The aim of this study was to assess the feasibility of visualising hot and cold tumours in Y-90 PET/CT and Bremsstrahlung SPECT/CT imaging, and to assess the influence of energy window selection on image usefulness. By using an anthropomorphic phantom we aimed to approximate a clinical setting, and by imaging it over 15 days to assess the impact of different activities on foci visibility.
Material and methods: The data was acquired using an anthropomorphic phantom including liver with two spherical tumours (one cold- with no activity, one hot). Liver and hot tumour were filled with Y-90 chloride. The activity in the liver ranged from 1431 to 38 MBq and in the hot lesion from 19.4 to 0.5 MBq. Nine imaging sessions were conducted, all including SPECT/CT imaging using 30 sec/ projection, high-energy collimators and three energy window settings (W1: 0-280 keV, W2: 100-200 keV, and W3: 100-200 keV comprised of four narrow emission windows), and PET/CT imaging according to clinical protocol (30 min/bed). Qualitatively, the visibility of the tumours was appraised based on the scores awarded by three independent observers. For the quantitative assessment, contrast-to-noise ratio (CNR) was calculated for both spheres in all images.
Results: We have found good correlation between the qualitative and quantitative assessments of the lesions visibility in most cases. For SPECT/CT imaging the cold tumour proved too small to be discernible (CNR <0.5) regardless of the Y-90 activity in the liver, while hot sphere was visible up to the fifth day of imaging for the best acquisition (energy window W2, CNR>4). Dividing the energy window (W3) yielded the worst results, which were not fully in agreement with the quantitative assessment. For PET/CT imaging, the cold tumour was only visible with the highest Y-90 activity (CNR>4), whereas the hot one was seen up to the tenth day of imaging (CNR>5).
Conclusions: In our study PET/CT provided better images for assessment of hot and cold foci visibility than SPECT/CT, however due to limited number of registered counts it is not without its limitations. CNR seems to provide a good quantitative measure of lesion's visibility, which is in agreement with qualitative assessment. Dividing the energy window for SPECT/CT acquisition did not improve the data, which suggests that further quality improvements must be obtained through other means, probably via more advanced scatter correction.
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PROTOTYPE DEEP-SILICON PHOTON COUNTING CT ENABLES IMPROVED IODINE SENSITIVITY AND QUANTIFICATION

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Purpose: A novel deep silicon-based (deep-Si) photon counting computed tomography (PCCT) device is being developed for whole-body CT applications. This paper demonstrates the increased sensitivity and consistent quantification of Iodine contrast material made possible by the design of the prototype CT system. Advances in diagnostic imaging facilitated by this new system may open the door to earlier and improved detection and diagnosis of subtle patient pathologies.
Material and methods: A novel prototype photon-counting CT device was used, which features a detector that uses silicon as the detector substrate (GE Healthcare) and a novel readout designed to detect photons across multiple energy bins. An anthropomorphic phantom (Gammex, Sun Nuclear Systems), constructed from water-equivalent background material was imaged using a protocol comprised of manual settings of kV, mA, rotation speed, and image filter. The phantom was imaged in both small (20cm) and large (40x30cm) configurations, simulating a relatively smaller and larger patient habitus, respectively. Eight solid one-inch diameter cylinders were inserted into the phantom at various regular locations around the phantom. The cylinders contained Iodine concentrations ranging from 0-20mg/ml, mimicking large vasculature containing progressively higher concentrations of Iodine. Acquired spectral data were reconstructed into material decomposition images using a prototype reconstruction algorithm. Circular region-of-interests (ROI) of similar size were placed in the centre of each cylinder at regular points along the image volume.
Results: In the Iodine(Water) image, the average ROI value for the 0.25mg/ml location was 0.24±0.14mg/ml, consistently differentiating the smallest iodine concentration from the water-equivalent inserts

with an inherent concentration of 0mg/ml. Similar accuracy in the average concentration was measured across iodine concentrations. These results indicate that this prototype photon-counting CT system with a deep-Si detector enables improved sensitivity to the presence of Iodine in concentrations up to at least twice as low when compared to prior dual-energy technology. In addition, the quantitative measurements of the higher-concentration Iodine inserts showed a similar enhanced sensitivity throughout the image volume when compared to dual-energy technology.
Conclusions: A novel deep silicon-based photon counting CT system enables far higher sensitivity to the presence of Iodine in addition to improved consistency in the measurement of Iodine. This twin ability hints at the potential for improved pathology detection and diagnosis using deep-Si detector technology.

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COMMISSIONING OF SYNTHETIC CT BRAIN IMAGES FOR THE IMPLEMENTATION OF AN MR-ONLY RADIOTHERAPY WORKFLOW FOR CNS PATIENTS

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Purpose: A synthetic Computer Tomography (sCT) image, generated entirely from Magnetic Resonance (MR) sequences, provides the means to deliver radiotherapy (RT) without introducing the geometric uncertainty characteristic of the image registration process between a CT and an MR. The elimination of the CT examination altogether from the RT workflow promises to cut down on planning time and costs, as well as enabling a better resource utilization of educated personnel. In addition, it results in a reduction of dose to the patient. The aim of this work was to commission a commercial sCT product (Philips MRCAT) for the brain while investigating its viability for an MR-only clinical workflow.
Materials and methods: An extra MR sequence for sCT generation was performed on 100 patients diagnosed with CNS tumours that otherwise underwent routine photon or proton radiotherapy. Contouring of tumour and organs at risk (OAR) on the sCT images was performed and compared retrospectively with the contouring on the CT/MR images. The dose distribution comparison was performed retrospectively for 25 glioma patients chosen from the pool of patients treated with photons.
Results: A mean Dice coefficient of 0,95±0,02 and 0,93±0,05 were obtained for brain and CTV structures, respectively. Moreover, the average Hausdorff distance was found to be less than 0,045 mm for both structures. Dose distribution comparison resulted in a mean dose difference of 0,6% for PTV and less than 1% for other OAR. D2% for cochleae and optical nerves differed as much as 5%. Bone artefacts were found in post-operative patients where the loss of signal due to metal implants, in or close to the skull, led to an erroneous thickening of the bone tissue in the sCT. This is of particular interest for cases where the GTV/CTV is located adjacent to the metal implant where a margin might have to be added to avoid underdosage of tumour tissue. Dose distribution comparison for such cases show no impact in mean dose to the PTV.
Conclusions: The sCT brain images can be used for contouring and dose distribution calculation with equal clinical confidence as in CT/MR based workflow. The uniqueness of this study due to the large cohort of patients helped provide a big enough sample of image artefacts which can be studied in detail. This process, apart from building confidence among the staff for handling this new technique, will facilitate decision making when MR-only workflow is implemented.

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BEAM MONITORING FOR ELECTRON FLASH BEAMS

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Purpose: Normal tissue sparing effect was demonstrated in ultra-high dose-rate irradiations (FLASH effect). The non-linearity of conventional transmission chambers hampers investigating the role of dose-per-pulse (DPP), instantaneous DPP, pulse duration and frequency, in triggering the FLASH effect and delays its clinical transfer. Within the FRIDA project, the University and INFN Torino are characterizing the performance of thin silicon sensors and associated readout electronics for electron beam monitoring in high dose-rates.
Materials and methods: Inversely polarized hybrid silicon sensors (segmented in 2.2 $mm^2$2 strips, 45/615 µm active/total thickness) are readout by a TERA08 chip, based on the recycling integrator architecture and developed to readout gas monitors in charged particle therapy. The signal from one sensor strip is split into the 64 chip channels and the measured current is obtained from all channels counts. The charge produced in silicon by electron FLASH irradiations was simulated; first tests were performed with electrons from an Elekta SL18 LINAC, entirely dedicated to research. Varying beam energies (4-18 MeV), distance to the source, sensor position in the beam field and dose-rates in the conventional range, the performance of sensor and readout in measuring the beam flux are being evaluated. Similar tests will be repeated after the upgrade of the LINAC, foreseen in the next months to produce high dose-rate electron beams (~1 Gy/µs pulse).
Results: Simulations of 6 MeV electrons interacting with thin silicon sensors resulted in around 0.4 keV/µm average energy released per electron, leading to ~10 nC produced charge for 105 Gy/s instantaneous dose-rate in a 3 µs beam pulse in a silicon of 2.2 mm^2 × 45 µm thickness. Preliminary tests with electrons of 4, 6, 10, 18 MeV up to 7 cGy/s conventional dose-rate confirmed the reproducibility of the system and the possibility to study beam profile and flatness. The present configuration of TERA08 (max 20 MHz/channel subtraction frequency; 200 fC charge quantum) can sustain up to 256 µA instantaneous current in the pulse and is expected to be linear up to tens of kGy/s dose-rates. An accurate calibration of the beam and the upgrade of the LINAC are ongoing.
Conclusions: The preliminary tests demonstrated the capability to measure the flux of electron beams in conventional dose-rates and promise to withstand dose-rates approaching FLASH ones. In the next months, silicon sensors with reduced active area and thickness and an updated version of the chip (TERA09) will be tested on FLASH beams.

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SEGMENTATION IN QUANTITATIVE DYNAMIC NUCLEAR MEDICINE: THE INSUFFICIENCY OF THE TG-211 OF THE AAPM

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Purpose: The Task Group 211 report of the American Association of Medical Physicists (AAPM) made a literature review of various segmentation techniques for nuclear medicine. These methods are

valid and strong in the context of static images; when faced with dynamic images, many challenges arise, and the user-dependency becomes problematic. One of the hypothesised reasons for this is the presence of movement between the timeframes.
Material: Many dynamic TEP acquisitions had been made on small animals (rats and mice) and other acquisitions have been made on a custom-designed dynamic phantom. The injected medical compound was either FDG or another radiopharmaceutical. The acquisitions lasted between 40 and 60 minutes.
Methods: For the analysis, three different classes of segmentation techniques have been used, according to TG-211: a gradient-based, statistics-based, and filling algorithms. The segmentations were performed on a specific reference timeframe and were static, i.e. the segmentation was not varying from one timeframe to the other.
To compare the results, the discrepancies between the segmentations were evaluated with various metrics, among which the Sørensen-Dice coefficient. Furthermore, since the segmentations are useful for pharmacokinetic analyses, the variations in the segmented volumes were assessed based on the quantitative impacts upon the time-activity curves (TACs).
Results: Concerning the segmentations themselves, the choice of timeframe upon which to base the algorithms has a great impact on the segmented volume. In the case of the small animals, this represents a large fraction of the total region of interest. In the case of the phantom, since the movement can be controlled and is known, the discrepancies are much less severe.
Concerning the TACs themselves, they are not as affected as had been expected: this could partially be explained by the fact that part of the voxels that are either present or not between segmentations are not the most active and, thus, have a lower impact on the statistics pertaining to the segmented region.
Conclusion: The TG-211 is a robust reference for static segmentations in nuclear medicine, but it is not trivial to apply its methods in a dynamic context. We conclude that the methods can be used, but it needs to be done carefully, as to be aware of the possible pitfalls pertaining to the transition from static to dynamic imaging.

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MEDICAL PHYSICS ESCAPE ROOM – UNLOCK THE DISCOVERY OF THE PHYSICS IN MEDICINE

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Purpose: An Escape Room has been designed and implemented by the University and INFN Torino in collaboration with the Italian Association of Medical Physics to raise interest in the general public about the application of Physics in Medicine, encouraging at the same time problem-solving, teamwork, and lateral thinking (fully included in the EU education policies, such as "Key Competences for Lifelong learning").
Methods: Three different environments have been designed, focusing on three fields of application of Physics in Medicine: cancer diagnosis, cancer treatment and research (mainly on innovative technologies for beam monitoring in charged particle therapy, i.e. the Torino research activities). Small groups of players are guided by a researcher or a medical physicist, who helps participants learning through playing. The guide activates the game by giving a first playing card in each environment with clues to solve puzzles, riddles, play games, and unlock padlocks hiding other playing cards to proceed in the exploration. At the end of each environment, the guide puts together all key concepts entailed in the playing cards and/or provided by short videos proposed during the exploration, to leave a take-home message. The Escape Room was put in practice during the European Researchers' Night (ERN 2021) for one night and one day, outdoors at the botanical garden in Turin (Italy) and during six days of the Science Festival (SF 2021) at the Royal Palace of Genova (Italy), indoors.
Results: Around 200 persons participated in the Torino edition and 400 in the Genova's one, mainly families and students from 11 years old to university students. The ERN and FS organizing committees reported a great success of the installation and several teachers contacted the Escape Room organizers to ask for more information about specific aspects their students encountered during the game. The experience gained during the first Escape Room in Torino helped improving puzzles and riddles for the second edition in Genova. Designing escape rooms is necessarily iterative, alternating experience and continuous improvement.
Conclusion: This experience has shown that an Escape Room is an excellent tool to communicate to the population the role of the medical physicist in research and clinical practice. This first attempt, addressing the general public, is now available to be used as an off-the-shelf tool, but could be modified and improved over specific areas of content, potentially becoming an innovative medical physics educational activity for medical physicists, radiology residents, or other categories.

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INTRODUCTION OF A DMS AND REMOTE QUALITY MONITORING SYSTEM IN A NATIONAL BREAST SCREENING PROGRAMME

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Purpose: The benefit of a Dose Management System (DMS) is well established. The requirements of European (2013/59/EURATOM) and transposed Irish legislation (SI256 2018) provide an imperative for such a system. In BreastCheck, the Irish National Breast Screening Programme, there was an additional requirement for a replacement remote Quality Control (QC) monitoring system. Two solutions from Qaelum (Leuven, BE), were chosen as the most appropriate solution for our dedicated mammography screening environment, DOSE (DMS) and MAMMO (Mammography specific technical quality monitoring). BreastCheck is the first national screening programme to implement this QC solution.
Material and methods: Incorporating these software solutions into the screening environment and refining functionality to our requirements formed the basis of a detailed project involving comprehensive collaboration with the vendor and ongoing application customisation continues.
Clinical and QC images feed into the application from 43 mammography systems. Interrogation of the DICOM header provides the clinical dose data along with all other relevant image acquisition parameters. QC images are analysed according to the approach of the EUREF Guidelines. While the provided dose management and QC solutions are comprehensive, detailed collaboration with the vendor has resulted in further development of both solutions to provide additional QC and dose data analysis for mammography.
Verification and validation of data from the installed equipment base presented some initial compatibility issues with simple resolutions proposed and implemented between modality vendor and application vendor. A radiographer centred approach to the

configuration of the application was adopted to ensure maximum engagement.

Results: This installation has facilitated quick and easy statistical overview of clinical and technical data. Annual dose surveys, previously based on 100 clients from each system have transitioned to continual dose monitoring, providing dose estimates from a much larger pool of data, as well as providing real time comparisons to local and national DRLs.

Weekly semi-automatic image analysis previously performed on QC images has transitioned to automated daily analysis, providing the system performance information sooner and allowing for immediate communication with radiographers on an issue.

Conclusions: The implementation of a dose and QC monitoring system provides significant benefit but requires extensive planning and collaboration with the vendor pre and post installation. The introduction of this application has facilitated a more streamlined approach to dose management, increasing dose awareness among users and raising the overall clinical and technical quality levels in the breast-screening programme.

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MACHINE LEARNING IN THE HISTOLOGICAL DIFFERENTIATION OF MEDIASTINAL BULKY LYMPHOMA WITH RADIOMIC [18 F]FDG PET/CT FEATURES

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One of the most common forms of hematologic cancers is mediastinal bulky lymphoma (MBL). It can be characterized using both morphological and functional imaging which represents one of the fundamental diagnostic tools available. An histological mediastinal lymphomas model is fundamental to offer solutions tailored to the single patient moving toward "personalized medicine", where Machine Learning (ML) can make the difference and bring a significant contribution to the whole process. This study makes use of Machine Learning algorithms on relevant features to predict the different histological types of the mediastinal bulky masses. The aim is to understand how PET radiomic features extracted from bulky masses may predict lymphoma histology and in the future support their histological diagnosis.

A cohort of untreated patients with a histopathological diagnosis of classical Hodgkin Lymphoma (cHL), Primary Mediastinal B Cell Lymphoma (PMBCL) and Grey Zone Lymphoma (GZL) were retrospectively evaluated in a monocentric study conducted by the nuclear medicine and hematology divisions of AOU Careggi (Florence, Italy).

To achieve the goal several ML-based techniques driven by radiomic features extracted from PET/CT images to perform classification were developed and trained. Lymphoma type identification pushes ML techniques due to the separation of non-completely disjoint classes. This histological-based limitation prevents to directly perform multiclass studies, requiring more complex solutions for classification. Binary classification between PMBCL and cHL has been carried out, then the resulting classifier has been enhanced with multiclass capabilities thanks to the definition of decision regions embedding the mixed characteristics of GZL.

Logistic Regression has shown the best performance in binary classification (PMBCL-cHL), reaching True Positive Rate (TPR) and True Negative Rate (TNR) greater than 80% on a totally independent dataset (test set). Despite the non-complete separation between GZL and the other two lymphoma types, upranking the Logistic Regression model allows to perform a multiclass separation, even with very good results:

- Correct identification of the two bordered classes greater than 70%, in particular of PMBCL, which represents the histotype with the worst prognosis, and therefore the most important to be identified by hematologists;
- Misidentification of PMBCL as cHL just under 5%, showing promising performance for diagnosis usage.

In this study it has been demonstrated that Radiomics combined with ML is able to discriminate different subtypes of bulky mediastinal lymphoma, providing good discriminative sensitivity. PET textural features correlate with histologic diagnosis in patients with mediastinal bulky lymphoma and thus may support anatomopathological analyses.

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APPLICATION OF MACHINE LEARNING AS FITTING METHOD IN PRE-THERAPY DOSIMETRY WITH I-123

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Purpose: The aim of this study is showing the feasibility of using Machine Learning (ML) as fitting-method to estimate the mean absorbed dose D to whole-body (WB) of pediatric patient administered with I-123, in order to get previsional information on radionuclide therapy.

Since personalized therapy is the best solution for patients, it is necessary to know a priori the maximum administrable activity, maximizing the mean absorbed dose to lesions and minimizing it to organs at risk. The pre-therapy dosimetry with I-123 allows to estimate D for patients undergoing radionuclide therapy with I-131.

Material and methods: According to MIRD schema, the mean absorbed dose to WB is D=A×S, where A is the WB cumulated activity and S the mean absorbed dose per unit cumulated activity.

The cumulated activity is the area under the biokinetic curve (AUBC), obtained through several dose rate measurements at different time points. In this study, two models were considered to fit biokinetic curves (BCs): Mono-Exopential (ME) and Bi-Eponential (BE) decay model.

Since I-123 and I-131 mark the same radiopharmaceutical, their effective decay constants differ just for the physical decay contribute. Once decay corrections were applied, ML models, already implemented in Python Scikit-Learn library, were used to classify BCs in ME or BE class and estimate AUBC.

Any ML model must be trained. Since few patients were available, it was necessary to simulate thousands of BCs to compose both training and test set, randomly generating model parameters in ranges defined through statistical studies. Gaussian noise was added on BCs points during tests to simulate measurements uncertainties. Two Logistic Regression Models were used for classifying BCs and thousands of Decision Tree Models for predicting fitting model parameters and calculating AUBC.

The possibility to reduce until 4 the number of time points composing the BCs was explored and test on patients were run.

Results: Compared to f-Test and AICc methods, ML shows better performance in classification, similar performance in AUBC prediction and stability despite of the number of time points reduction, while f-Test and AICc performance considerably decreases.
Conclusions: ML shows high performance in classification and AUBC estimation, even reducing the number of time points. This leads to the feasibility of reducing the number of dose rate measurements, making hospitalization more comfortable for patients, reducing workers' exposure to radiation, gammacameras occupancy and hospital costs. Moreover, especially for pediatric patients, not every planned measurements can be done, because of co-operation lack.

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HIGHER DOSE TO THE TUMOR GIVES SURVIVAL ADVANTAGE IN HCC BCLC B PATIENT PERFORMING SIRT RESPECT TO DEB-TACE

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Purpose: to evaluate the difference in overall survival (OS) among patient that performed drug eluting microspheres trans-arterial chemo-embolization (DEM-TACE) and selective internal radiation therapy (SIRT) of liver hepatocarcinoma in a BCLC B patient population.
Materials and methods: patients performed SIRT with both Sir-spheres and Thera-sphere devices. All treatments were performed selectively. Patients performed a pre-treatment mapping with 99mTc-MAA. The activity to be injected was calculated based on expected dose in the lungs, in the normal liver and in the tumor. Tumor was delineated in CT or MRI images. Patients for whom tumor was not delineable in MRI/CT were not included in this study. Cox model was applied to Overall survival (OS).
Results: 183 patients were included in the study: 49 performing SIRT (26 with Sir-spheres and 23 with Thera-sphere) and 134 DEM-TACE. Median OS was 15.1 months (range 1-68 months). The two groups (SIRT vs DEM-TACE) were homogeneous per albumin 3.5±0.5 g/dl and 3.7±0.7 g/dl (p=0.12), bilirubin 1.1±0.7 mg and 1.3±0.9 mg (p=0.19), and INR 1.1±0.1 mg vs 1.2±0.2 mg group (p=0.06) while age was lower in SIRT 65.6±10.8 versus 69.8±9.1 years (p=0.02). There was a lower fraction of Child-Pugh score 5 vs 6-7-8 42% vs 45%. Median OS were 14.2 vs 15.5 months for SIRT and DEM-TACE. TACE patients had a median OS of 15.5 months. The two risk groups with high and low dose, using cutoff-values for sir-spheres and therasphere used in literature (120 and 205 Gy), had a median OS of 13.7 mo (29 pts with low doses) and 20.2 months (20 pts with high doses) (Log-rank=0.009). In multi-variate analysis with Cox model only TACE vs high-dose vs low-dose SIRT were identified as significant. Low-dose group vs DEM-TACE had a HR=0.40 (95%CI=0.14-1.02, p=0.05) while high-dose group vs DEM-TACE had a HR=1.79 (95%CI=1.00-3.12, p=0.05).
Conclusion: BLCL B patients treated with SIRT and TACE have similar OS. If high dose is delivered to the tumor a far better OS is achieved.

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A 14-YEARS FOLLOW-UP OF OCCUPATIONAL RADIATION DOSES IN AN INTERVENTIONAL CARDIOLOGY DEPARTMENT

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Purpose: There was an increasing concern regarding occupational radiation exposure of the interventional cardiologists, recognized as a high-radiation-risk practice, during the last two decades. The purpose of this study was to investigate the dynamic in the personal dosimetry records of the medical staff in one Department of Interventional Cardiology.
Material and methods: Follow-up of interventional cardiologists' occupational radiation doses was performed in a department, currently performing more than 2000 procedures per year in two catheterization laboratories. The study was performed during the period 2007-2020 y and covered more than 30 interventional cardiologists. For each of the cardiologists all personal dose records were studied. The number and complexity of more than 30 000 interventional procedures were investigated, classified and analyzed. Routine personal dose monitoring was performed using TLD dosimeters worn under the lead aprons.
Results: All procedures were divided in two groups: diagnostic and interventional. The data from occupational dosimetry were grouped in three different time periods for the purposes of analysis. First period (2007–2009): with good teamwork and experienced team, leading to lower occupational doses. Second period (2010-2011): with constantly change in the team members and poor teamwork, leading to increase of the exposure for some cardiologists. Third period (2012-2020): when a new team started their progress and the development of a good teamwork with experienced interventional cardiologists and fewer, but constant number of team members.
The last period started with significantly increase in the individual dose for one of the cardiologists, up to 19.5 mSv for 2012 and 19.07 mSv in 2013, close to the regulatory dose limit of 20 mSv per year for an annual personal dose. This trend was following the changes in the organization of the department and the team members - uneven distribution of the number of patients and uneven distribution of the most complicated interventional procedures performed by the different cardiologists. The observed trends prompted actions on better organization and control. A better team work and an introduction of a program for increased radiation protection awareness in 2014, resulted in 3-fold decrease in personal doses for some of the staff members for the last years.
Conclusion: The evaluation and follow-up of occupational doses should be considered as an important part of the quality assurance programs. Our survey for interventional cardiologists who are routinely using their personal dosimeters, showed significantly increased radiation protection awareness for the last seven years.

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DOSIMETRIC EVALUATION OF GAS POCKETS ELECTRON DENSITY IN ONLINE ADAPTIVE MRGRT

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Purpose: The aim of this study is to evaluate the influence of gastrointestinal gas pockets during online adaptive (OA) workflow in magnetic resonance guided radiotherapy (MRgRT) and dosimetric impact in electron density (ED) map correction in stereotactic OA treatment of upper gastrointestinal (GI) tumors.
Material and methods: CT scans of patients affected by upper GI tumors undergoing SBRT were retrospectively evaluated. The analysis was performed by contouring the GI Organs at Risk (GIOARs), including stomach, small bowel, colon and gas pockets inside them (GAS). GAS structures in different GIOARs were analysed in terms of Hounsfield units' (HU) mean values and interquartile range (IQR). The distribution of average gas HU values included in each organ has been compared with the other organs' one in terms of Wilcoxon test to evaluate differences (p-value > 0.05). Values obtained were compared with the calibration curve of our CT-scanner to obtain the ED values. Mean value of HU for GAS structure of all patients was converted in ED (GIGED). 3 different treatment plans were calculated for each patient keeping all other plan parameters unchanged and forcing the GAS structure EDs with:
1 the conventional AIR electron density value (0.0012)
2 the water electron density value (1)
3 the GIGED value obtained in our study (0.4)
Dose distribution for each plan was compared with others in terms of gamma analysis. In addition, a parameter called ACTIVE GAS VOLUME (AGV) was calculated as the intersection of the GAS structure with the isodose of 5% of prescription dose to evaluate the volume of gas invested by beam path.
Results: 23 CT scans of 23 patients were evaluated for this analysis. Considering all patients mean HU of GAS structure is equal to -619.4 with an IQR of 116.5. Regarding the different organs we have obtained (IQR in parentheses) -606.6 (124.5) for gas in colon, -587.2 (243.5) for stomach and -613.9 (99.8) for small bowel. P-value calculated for Stomach gas vs. Colon gas comparison is 0.6287 while Stomach vs. Small Bowel and Small Bowel vs Colon comparisons are 0.6013 and 0.7444 respectively. Values of gamma in dose distributions' comparison with conventional air ED and GIGED are found to be inversely proportional to AGV.
Conclusion: Gastrointestinal gas ED does not depend on the GIOARs in which the gas is located. Dosimetric impact of switching ED from conventional to GIGED depends on the AGV parameter.

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SIMPLIFIED DOSIMETRY IN LU-177-DOTATATE THERAPY

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Purpose: To investigate the feasibility of simplified post-therapeutic dosimetry protocols for tumor volumes and kidneys after Lu-177-labeled peptide receptor radionuclide therapy (PRRT) of neuroendocrine tumors. Absorbed doses were calculated using various single-point dosimetry approaches and using patient-specific absorbed dose-per-activity values $(A/D)_1$ determined for the first treatment cycle.
Material and methods: A total of 39 patients with neuroendocrine tumors who underwent 146 Lu-177-DOTATATE treatment cycles were included in the study. All patients underwent one early (24h) and one late (7d) SPECT/CT acquisition following each treatment cycle. Absorbed doses were calculated for subsequent treatment cycles using $(A/D)_1$ values and corresponding administered activities. Single-point dosimetry was performed using the 24h or the 7d SPECT image with a fixed effective half-life (Teff) (median value of patient cohort) or using a patient-specific Teff determined from the initial treatment cycle. All results were evaluated against the "true" doses, i.e. doses calculated using the 24h and 7d SPECT images for all cycles.
Results: Single-point dosimetry for kidneys was most accurate when using the 24h SPECT image for which the median of the ratios in total absorbed doses in relation to the "true" doses were 1.00 (IQR: 0.95-1.04) and 1.01 (IQR: 0.97-1.05) when using the fixed Teff of 52h and the patient-specific Teff from the first cycle, respectively. For tumors, single-point dosimetry was more accurate when using the 7d SPECT images with median ratios in total dose of 0.98 (IQR: 0.94-1.00) for 7d with fixed Teff of 109h and 1.00 (IQR: 0.98-1.03) for 7d with patient-specific Teff from the first cycle. The medians of the ratios between total absorbed doses calculated using the $(D/A)_1$ values and the "true" doses were 1.00 (IQR: 0.91-1.05) and 1.09 (IQR: 0.98-1.32) for kidneys and tumors, respectively. Tumor doses were increasingly overestimated as the "true" doses slowly decreased with treatment cycle whereas the difference in kidney dose was relatively constant.
Conclusions: Single-point dosimetry proved feasible when using early 24h SPECT images for kidney dosimetry and when using late 7d SPECT images for tumor dosimetry.

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LESION DETECTION WITH SPECTRAL IMAGING AND DEEP LEARNING IMAGE RECONSTRUCTION

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Purpose: To investigate if Gemstone Spectral Imaging (GSI) with deep learning image reconstruction (DLIR, TrueFidelity) improves liver lesion detection compared to single energy (SE) with DLIR and GSI with iterative reconstruction (IR, ASiR-V).
Material and methods: An anthropomorphic liver phantom (The Phantom Laboratory, Salem NY) was scanned on a GE Revolution CT Apex edition (GE Healthcare, Milwaukee). Dose modulation was used and noise index was adjusted to get CTDIvol within 11.7-12.0 mGy for SE (80, 100 and 120kVp) and GSI scans. Images were reconstructed in 2.5 mm slice thickness, with DLIR of medium strength and 50% IR (GSI only). The monoenergetic levels of 120kVp-like (74keV), 100kVp-like (68keV), 55keV and 40keV were used in addition to iodine maps.
The liver phantom was equipped with eight inserts containing cylinders with different concentrations of iodine (1.36/1.56/1.75 g/l). Cylinder diameters were 3, 5 and 10 mm. All scans were repeated with the inserts with cylinders replaced by homogenous inserts.
Pairwise cropped CT images of each insert with and without lesions were presented to 17 readers using a two-alternative forced choice approach. Window settings were fixed and adjusted to energy level. Readers were instructed to select the signal-present image (i.e., containing lesions) for 438 image comparisons. Sensitivities were calculated.
Results: *5mm lesion:* At the energy level of 120kVp(-like), GSI with DLIR increased sensitivity compared to GSI with IR and SE with DLIR (90% vs 78% and 81%). At the energy level of 100 kVp(-like), GSI with DLIR and SE with DLIR resulted in similar sensitivity (88% and 87%), while GSI with IR resulted in inferior sensitivity (80%). At 40keV and 55keV, DLIR increased sensitivity compared to IR (90% vs 78% and 92% vs 81%, respectively). Sensitivity for SE at 80kVp and GSI with 55keV both with DLIR was comparable (93% and 92%).
3mm lesion: For the smallest lesion, GSI with IR resulted in superior sensitivity compared to SE/GSI with DLIR (120kVp(-like): 75% vs 68%/59%; 100kVp(-like): 73% vs 39%/59%).

The 10 mm lesion and iodine maps are work in progress.
Conclusions: GSI improved lesion detection compared to SE. GSI with DLIR improved detection of 5mm lesions compared to SE with DLIR and GSI with IR. For 3mm lesions, GSI with IR had the best sensitivity compared to both SE and GSI with DLIR.

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FEASIBILITY OF WATER EQUIVALENT PATH LENGTH ANALYSIS IN ADAPTIVE PROTON THERAPY OF LOCALLY ADVANCED NON-SMALL CELL LUNG CANCER

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Purpose: Anatomical changes may affect the delivered dose in proton therapy of locally advanced non-small cell lung cancer (LA-NSCLC). Analysing the water equivalent path length (WEPL) of protons in the patient could aid in deciding if adaptions are needed to retain plan quality. The feasibility of WEPL in adaptive proton therapy of LA-NSCLC was evaluated by studying the correlation between WEPL changes and target dose degradation during the treatment course of intensity modulated proton therapy (IMPT).
Material and methods: 15 LA-NSCLC patients treated with IMRT to 60 or 66 Gy (2 Gy/fx) were included. Repeat CT (rCT) scans were acquired during the first and third week (w1/w3) of treatment, and registered to the planning CT (pCT). One patient missed the rCT of w3, hence 29 rCTs were included. 3D-robust IMPT plans were created retrospectively on the pCTs and recalculated on the rCTs.
Calculation of WEPL in CT scans was performed using a stoichiometric calibration, obtaining a conversion from CT number to proton relative stopping power (RSP). The WEPL was evaluated to all points at the distal edge of the CTV structure. The change in WEPL (ΔWEPL) from the pCT to each of the rCTs was compared to the change in CTV V95 (ΔV95) from the original to the recalculated IMPT plans. The ΔWEPLs were aggregated to the mean and the 95th percentile of |ΔWEPL|, and the percentage of points at the distal CTV edge with > 3 mm and > 10 mm WEPL changes. The Spearman's correlation coefficient and the Mann-Whitney U test were applied for correlation testing and comparison between groups, respectively, with significance level $p = 0.05$.
Results: With the obtained calibration curve, RSP values were predicted with a mean relative error of 4.6%. The median of the mean |ΔWEPL| for all patients was 5.4 mm in w1 and 4.5 mm in w3. Among the 29 recalculated IMPT plans, 7 had ΔV95 < −1%. The ΔWEPL was not significantly different for these than for the plans with less target dose degradation (w1: $p = 0.343$, w3: $p=0.885$). There was no significant correlation between ΔV95 and ΔWEPL, except in terms of the percentage of points with ΔWEPL < −10 mm ($p = 0.019$).
Conclusion: Changes in WEPL to the distal edge of the CTV did not correlate with changes in CTV V95. WEPL is not a feasible tool in adaptive proton therapy of LA-NSCLC with robust optimised IMPT plans.

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MEDICAL AND OCCUPATIONAL DOSIMETRY DURING INTERVENTIONAL PEDIATRIC CARDIOLOGY PROCEDURES: A MONTE CARLO APPROACH

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Purpose: In this work, we evaluated the medical and occupational doses during a pediatric cardiac interventional radiology procedure, employing virtual anthropomorphic phantoms, with 1-, 5- and 10-year-old, as well as two adult phantoms to represent the medical staff.
Material and methods: Each scenario was composed by two phantoms, the physician and the patient, coupled to the MCNPX 2.7.0 Monte Carlo code. The exposures were evaluated for six different projections and beam setups, normally employed in angiographic procedures - tube voltages of 80, 100 and 120 kVp. The conversion coefficient values (CC) for radiation protection quantities were obtained to access the medical and occupational exposures. These CC values are determined as the ratio between the equivalent, or effective dose, to the dose-area product.
Results: The patient's organs with the highest effective dose contributions were the lungs, stomach, oesophagus, liver and heart. To the physician the most exposed organs were the breast (female), brain, thyroid, lungs, stomach and bone marrow. For the physician, the results are strongly related to the type and design of Personal Protective Equipment (PPE) used. The lead apron may reduce the doses up to 100%, and the use of the face protector may reduce the eye lens equivalent dose up to 89%. The brain effective dose may also be reduced by 16% with the use of a lead cap. The CC values were also influenced by the patient size, beam projection angle, and radiographic technique. The dose distributions inside the room were also depicted in a 3D map, ensuring the staff the possibility of choosing safer positions, without compromising the procedures.
Conclusions: Through the results presented in this study, we may conclude that the CC values for the patients increased with increasing the X-ray tube voltage and decreased with the increasing of the patient age. Therefore, a low tube voltage must be selected, taking into account the image quality. Finally, our results pointed out the importance of adequate PPE, as well as the doses to the pediatric patients, employing modern virtual anthropomorphic phantoms.

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THE ROLE OF THE MEDICAL PHYSICIST IN RADIOTHERANOSTICS

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Purpose: Medical physicists (MPs) and Medical Physics Experts (MPEs) can have a significant role in the discovery, promotion and implementation of emergent technologies. Yet, so far their involvement in radiotheranostics is minimal. As a consequence, radiopharmaceutical therapy treatments are prescribed and evaluated only by physicians. The different areas in which medical physicists can change the field of radiotheranostics will be presented and discussed.

Material and methods: MP potential research areas and the need to collaborate with other professionals, mainly radiochemists and nuclear medicine physicians, will be examined. Requirements in the European Basic Safety Standards (Council Directive 2013/59/Euratom of 5 December 2013) - by now incorporated in the national radiation control regulations of the European Union countries - concerning MPE functions and responsibilities for patient dosimetry and radiation safety in nuclear medicine procedures will be reviewed. The position paper of the European Association of Nuclear Medicine (EANM) proposing to distinguish three levels in compliance to the optimization principle of the EU directive, "inspired by the indication of levels in prescribing, recording and reporting of absorbed doses after radiotherapy defined by the International Commission on Radiation Units and Measurements" will be exposed and analyzed. MP and MPE needs in education and training areas to cover the radiotheranostic field and problems to attain professional recognition will be considered.
Results: MP and MPE roles that will be explored include: searching for new radiotheranostic agents, assessing methodologies of radionuclide cyclotron production, designing new radionuclide generators, suggesting and testing biomolecules' radiolabelling techniques, developing new radionuclide detectors and imagers, standardizing activity measurements, evaluating radiopharmaceutical biokinetic distributions, examining clinical diagnostic and therapeutic radiopharmaceutical protocols, determining individualized organ doses, and optimizing radiation protection. Dosimetric issues arising when radiopharmaceutical therapy is combined with external beam and brachytherapy for cancer treatments will be discussed. The potential impact of current and emergent treatments will be appraised. Changes in MP and MPEs education and training curricula as well as additional certification requirements will be suggested.
Conclusion: The field of radiotheranostics is an emergent field with scientific, technical, educational and professional challenges faced by medical physicists working in basic or applied research, industry and clinical practice.

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MACHINE LEARNING BASED PREDICTION AND CLASSIFICATION OF VMAT PLANS DOSIMETRIC ACCURACY USING PLAN COMPLEXITY AND LOG-FILES ANALYSIS

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Purpose: We developed a machine learning model based on log files analysis and complexity indexes to predict and classify the dosimetric accuracy of volumetric arc therapy (VMAT) plans.
Methods and materials: 1302 VMAT arcs from 651 treatment plans were analysed. All VMAT plans were generated using the Pinnacle Autoplanning optimization engine. Three complexity metrics including the aperture area variability (AAV), leaf sequence variability (LSV) and modulation complexity score (MCS) were considered as inputs to the model. Patient-specific QA was performed using the LinacWatch (Qualiformed) software, able to analyze the dynamic log files generated by the linac following the delivery of each radiation VMAT arc treatments and to supply the delivered integral fluence. The comparison of TPS-predicted and log-files based measured fluences was performed using γ-analysis at 2%(local)/2mm criterion in terms of mean γ-values (γmean) and percentage of points with γ-value smaller than one (γ%). A LASSO regression model was used to explore correlations among features. A kernel regression model was developed aiming to predict individual γ% and γmean values. Multinomial logistic regression (LR) and support vector machine (SVM) models were developed to classify QA results as "pass" (γ%>90% or γmean<0.5), "control" (80%<γ%<90% or 0.50<γmean<0.75) and "fail" (γ%<80% or γmean>0.75). Training, validation and testing groups were used to evaluate the model reliability. ROC curves were used to determine the complexity threshold values for approval, control or rejection of plans.
Results: Prediction accuracy in terms of root mean squares of residuals for γ%, as provided by kernel regression, was found 2.1% and 2.2%in the training and testing cohorts, respectively. For γ%, LR provided a percentage of well classified results of 92.9%, 94.6%, 87.4% and 90.0%, 96.2%, 84.4% in the training and testing cohorts for the 'failed', 'control' and 'pass' categories. Similarly, SVM provided a percentage of well classified results of 95.2%, 95.7%, 86.7% and 90.0%, 96.2%, 84.4% in the training and testing cohorts, respectively. The optimal MCS threshold value for the identification of failed plans was found 0.130, providing sensibility and specificity of 0.994 and 0.952, respectively. The optimal MCS threshold for the reliable plans was found 0.270, providing a sensibility and specificity of 0.925 and 0.922, respectively.
Conclusion: Machine learning can accurately predict the dosimetric accuracy of VMAT treatments. A traffic light protocol was proposed to "a-priori" classify over-modulated plans to be rejected (MCS<0.130) and robust plans that don't require pre-treatment QA (MCS>0.270).

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PRELIMINARY EVALUATION OF A NON-CONTRAST-ENHANCED MRI PROTOCOL OF THE THORACIC AORTA, INCLUDING A 4D FLOW SEQUENCE

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Purpose: Because of their long-term environmental and health risks, the use of gadolinium-based contrast agents in MRI needs to be re-assessed. A new aortic follow-up protocol made of non-contrast-enhanced MR angiography (NCE-MRA) and 4Dflow was validated and implemented in clinical routine, replacing the classical contrast-enhanced MR angiography (CE-MRA) protocol.
Methods: 22 consecutive patients who underwent the aortic follow-up MRI were included in the study (February-August 2021). A new dynamic TrueFISP-3D NCE-MRA sequence was tested as an alternative to the current reference FLASH-3D sequence with contrast injection. Aortic segment diameters and aortic volumes were measured by several radiologists. A qualitative assessment was also performed. The feasibility of integrating a 4Dflow sequence with a compressed sensing acceleration technique in clinical practice was also evaluated. To this aim, the CardioflowQA phantom was used to validate the image quality before clinical use. Wall shear stress (WSS) and pulse wave velocity (PWV) were evaluated and 5 volunteers were included for reproducibility.
Results: The median acquisition time of the NCE-MRA was 4'30". An excellent correlation was observed between the two sequences for aortic segments (r=0.99, p<0.0001, bias<1mm) and volumes (r=0.98, p<0.0001, underestimation=-8.4cm3). The study showed an excellent inter-observer agreement. The average acquisition time of the 4DFlow was 3'54". Good reproducibility was observed for the WSS and PWV for the control group and coherent values for the patient group.
Conclusion: A gadolinium-free aortic follow-up protocol providing quality angiography and new haemodynamic biomarkers has been implemented in the clinical routine.

Limitations: The study is limited by the very short study time and the number of patients.

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EQUIVALENT DOSE RATE FROM PATIENTS UNDERGOING NUCLEAR MEDICINE PROCEDURES: WHAT'S THE NEWS ON RECENTLY-INTRODUCED RADIOPHARMACEUTICALS?

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Purpose: The aim of this work was to compare dose rate measurements from injected patients in the Nuclear Medicine Department of the Santa Croce and Carle Hospital and Umberto Parini Hospital with the literature and to study the exposure rate from patient injected with recently-introduced radiopharmaceuticals: 99mTc pyrophosphate (PYP), 11C-methionine, 68 Ga-DOTA, and three radiopharmaceuticals used for prostate cancer imaging 18F-PSMA1007, 68Ga-PSMA11 and 11C-choline.
Materials and methods: 151 patients were measured with a ionization chamber . Dose rates were measured in patients immediately before the acquisition. 68Ga-PSMA11 and 68Ga-DOTA were performed with a early and late acquisition of the images at 90 and 150 min respectively. Dose rates were measured at 30 cm and 1 m from patient's thorax with the patient upstanding. Average dose rates are reported.
Results: 81 patients of 8 conventional nuclear medicine procedures were measured with at least 10 patients each. Compared to Bartlett 2013, we found dose rate differences less than 20% for renal, myocardial thyroid, and bone scintigraphy with 99mTc. Average dose rate in the eleven 99mTc-PYP patients was 91 µSv h-1/GBq at 30 cm and 14 µSv h-1/GBq at 1 m after 3 hours from injection. 70 patients underwent PET/CT procedure: the dose rate at 30 cm and at 1 m was 271 µSv h-1/GBq and 43 µSv h-1/GBq for patients injected with 18F-FDG respectively, 252 µSv h-1/GBq at 30 cm and 40 µSv h-1/GBq at 1 m for 11C methionine, 106 (30) µSv h-1/GBq at 30 cm and 42 (12) at 1m for 68Ga-DOTA respectively for early and late (in brackets) acquisition. In case of radiopharmaceuticals used for prostate cancer imaging the dose rate were: 498 µSv h-1/GBq at 30 cm for 18F-PSMA 1007, 106 (43) µSv h-1/GBq at 30 cm and 35 (13) at 1m for 68Ga-PSMA11 respectively for early and late (in bracket) acquisition, 449 µSv h-1/GBq at 30 cm and 137 µSv h-1/GBq at 1 m for 11C choline .
Conclusions: The measurements showed a good agreement with the literature values. Starting from these data the radiation dose to the potentially exposed people will be evaluated to check the 59/Euratom constraints. Further studies will be carried out in fluorine 18F choline from June 2022.

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RADIOBIOLOGICAL DOSIMETRY OPTIMIZATION FOR HIGH RISK PROSTATE CANCER

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Purpose: Differently from the most widely used radiotherapy treatment planning dosimetry optimization based on dose-volume histogram objectives (O-HDV), the radiobiological optimization (O-Rb), adopts the generalized uniform equivalent dose, gEUD, to create a more efficient cost function (CF).
gEUD=∑_i(v_i×D_i^a)^(1/a)
where a is the volume-effect parameter. The choice of a is crucial to control the HDV area in which the CF acts. For each optimization objective, a is decided by the user, but currently there isn't much bibliography helping on this.
Our goal is to find a template of a-values that maximizes the quality of the dosimetry. We focus on high-risk prostate cancer (HRPC) treatments.
Material and methods: We consider 30 approved treatment plans of HRPC VMAT optimized with O-HDV or O-Rb (Eclipse, Varian).
We define the quality of a dosimetry with the Dosimetric Quality Index (DQI), created in our institution. DQI, based on the Uncomplicated Tumor Control Probability, is a function that combines the Tumor Control Probability and the Normal Tissue Complication Probability of the ORs: femoral heads (FH), bladder and rectum. The DQI reference value was obtained from a set of Reference Dosimetries approved in our service (RD).
First, we optimize considering only the PTV, to later evaluate the dosimetric gain when the OR are included. Next, for each OR, we perform series of dosimetries differing from each other only in the a-value, covering the range of a-values for which the maximum and mean absorbed doses (Dmax, Dmean) are more sensitive. We represent these variables against a, and look for the best polynomial fit. We obtain the a-values associated with the lowest Dmax and Dmean. With them, we optimize considering the OR. This process involved the performance of 1100 dosimetries. We analyse the MU and the DQI of these dosimetries and compare them with the RD. The results are analysed using R language and compared using the Wilcoxon test.
Results: The a-values associated with minimum Dmax are 32, 40, 38; and with minimum Dmean, 0.7, 0.4, 0.1, for FH, bladder and rectum, respectively.
Using this template, we obtain a 10% reduction in the MU and a 90% increase in the DQI with respect to RD.
Conclusions: The template of optimal a-values leads to higher quality dosimetries with respect to O-HDV, as determine by our DQI, and with less MU, which implies shorter and more reproducible treatments. These results has led to great benefits in our clinical practice in many aspects.

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3D IMAGE QUALITY CHARACTERISATION IN COMPUTED TOMOGRAPHY

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Purpose: Computed Tomography (CT) devices acquire and reconstruct volumetric data. In this condition, a deeper and more robust image quality characterisation needs to be assessed with three-dimensional metrics, in particular when iterative reconstruction (IR) algorithms are used.
Materials and methods: A last generation computed tomography equipment, using both Filter Back projection (FBP) and Iterative reconstruction algorithms (IR), has been investigated using two dedicated phantoms: a cylindrical water-filled phantom equipped with spherical details of different contrast and materials and a cylindrical homogeneous phantom. Both phantoms have been scanned with different acquisitions parameters, dose levels collimation widths and pitch. Furthermore, each acquisition has

been reconstructed using different reconstruction algorithms, filters and slice widths, in order to characterise their effects on image quality.
Three-dimensional metrics, such as 3D Target Transfer Function (TTF), 3D Noise Power Spectrum (NPS), 3D Low Contrast Detectability (LCD) with Statistical Method (SM), 3D Noise Texture Deviation (NTD), have been analysed and used to evaluate the 3D generalisation of detectability index d' to assess image quality for relevant clinical task. Furthermore, potential dose reduction achievable with IR compared with FBP has been discussed.
These results have been compared with the corresponding standard 2D metrics.
Results: 3D TTF highlights an anisotropy of spatial resolution (up to 35%) for both high contrast and low contrast details, highly affected by CTDI values, slice thickness and reconstruction algorithm. Similarly, other metrics such as NPS, LCD and NTD show similar dependencies. At the same time, 2D metrics results to be unable to take into account these effects.
3D detectability index highlights its dependencies from anisotropy of image properties, giving a lower achievable dose reduction (from 25% to 60%) compared to the same analyses performed with 2D detectability index; results are more consistent with clinical data.
Conclusions: 3D metrics results to be able to better characterised image quality compared to standard 2D metrics, allowing a deeper understanding of CT images. Furthermore, 3D detectability index gives results more consistent with clinical data.

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AD HOC MRT PHANTOM TO ASSESS GEOMETRIC ACCURACY FOR STEREOTACTIC RADIOTHERAPY
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Purpose: For stereotactic radiotherapy we rely heavily on multimodal imaging. For cranial stereotactic radiotherapy we need MRT images to delineate the tumor region as well as organ at risk structures. As we know MRT images may show geometric distortions. The geometric distortions depend on various parameters, some of them are systematic parameters linked to the MRT scanner. Depending on the acquisition sequence as well as on the imaging coil the geometric accuracy may strongly influence the apparent position of tumor tissue and also anatomical structures. For the safe use of focal therapy concepts we needed to quantify the distortions.
As many clinical departments have experienced, sometimes it is not possible to purchase new equipment in short time spans even though the need is imminent. So we developed a phantom from commonly available materials to quantify geometric distortions in our MRT scans.
Material and methods: Several concepts for phantoms were tested. MRT images were recorded using the head coil and several MRT sequences. For reference a set of CT images was recorded from the same phantom. To find geometric distortions the images were evaluated using an independent image processing software.
Results: An MRT compatible phantom was developed. The phantom is cylindrical in shape and filled with distilled water. It contains regular structures in two orthogonal planes. One MRI sequence "MP-rage" has proven to be geometrically accurate. The sequence will be used for all stereotactic protocols. Also distortion correction provided by the MRT device was evaluated and will be used in the clinical routine.
Conclusions: In this talk I will present a way to develop your own stereotactic MRT phantom and I will share our approach to MRT QA in radiotherapy.
We showed that it is possible to develop custom built MRT phantom using only materials which are easily available. With this phantom we developed a method for quality assurance. So whenever a coil is changed or a new sequence is implemented we can validate the changes in terms of geometric accuracy. We identified the suitable MRT sequence which satisfies the high demands of stereotactic radiotherapy.

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OPTIMIZATION OF SPECT PROCEDURES VIA DEEP CONVOLUTIONAL NEURAL NETWORK
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Purpose: Nuclear medicine imaging procedures are characterized by long acquisition times. The number of acquired projections correlates with the acquisition time and reconstructed image quality. Therefore, acquisition time is parameter to be optimized during comprehensive optimization process. This study assesses the feasibility of using a deep convolutional neural network (DCNN) to improve the reconstructed SPECT image quality. The image quality similar to the one obtained with twice the number of planar projections should be achieved, which in turn implies halved acquisition time.
Material and methods: The DCNN was implemented in the PyTorch and trained using 36 acquisitions of the multiple head registration/center of rotation (MHR/COR) phantom and 72 acquisitions of the Jaszczak phantom with, overall, 6768 projections. The network is to produce a synthesized projection that is to approximate the missing n-th projection given a pair of (n−1, n+1) acquired projections. Synthesized projections were compared to projections from a baseline method, which generated the missing projection with a pixel-by-pixel arithmetic mean of neighbour projections. The obtained synthesized projections were compared across several similarity measures: Structural Similarity Index Measure (SSIM), Visual Information Fidelity (VIF), Haar Perceptual Similarity Index (HaarPSI) and Mean Absolute Error (MAE).
The final augmented acquisition composed of acquired and synthesized projections was reconstructed using an iterative reconstruction algorithm. Its tomographic spatial resolution and contrast were compared to the reconstruction of the original image and the baseline image.
The FWHM of 5 point-spread functions of MHR/COR phantom were compared for reconstructed original, DCNN generated, and baseline images of MHR/COR phantom generated as described for Jaszczak phantom.
Results: DCNN synthesized projections achieved higher SIM, VIF, HaarPSI and MAE scores when compared with original and baseline projections. Augmented images of Jaszczak phantom achieved better tomographic image quality results than baseline images or acquired images. The image quality parameters of augmented image were comparable to the tomographic images reconstructed from real acquisitions with twice as many projections. Analysis and comparison of results for MHR/COR phantom showed that the DCNN could produce images with spatial resolution better than baseline and comparable to the original acquisitions.
Conclusions: The study demonstrates the positive results in applying DCNN trained on Jaszczak and MHR/COR phantom images: the improvements in reconstructed SPECT image quality and results

comparable to acquisitions with twice as many projections. The application of deep learning in nuclear medicine shows a clear potential in acquisition time optimization process with retaining satisfactory image quality results.

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CHARACTERIZATION OF AN OPTICALLY STIMULATED LUMINESCENCE SOLUTION FOR UHDR "FLASH"-DOSIMETRY

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Purpose: The FLASH-effect, in which dose delivery at ultra-high dose rates (UHDR; >40 Gy/s) over very short treatment time (<200 ms) leads to a strong decrease of normal tissue radiotoxicity with preservation of the antitumoral effect, has regained serious interest after the 2014 paper from Institut Curie and CHUV. However, the lack of accurate UHDR dosimetry prevents the understanding of the radiobiological mechanisms hereof. In this work we present an optically stimulated luminescence (OSL) system as a fast and reusable 2D reference dosimeter for UHDR electron beams.
Materials and methods: We characterized three phosphor-coated films (Agfa, Belgium) with different radiation sensitivity, due to different phosphor concentration, crystal size, thickness and coating weight. Their linearity with dose and dose per pulse, and stability with pulse repetition frequency (PRF) were investigated using a 9 MeV UHDR electron beam generated by the ElectronFlash (S.I.T., Italy) accelerator. Doses ranged between 6-14 Gy, 3.5-300 Gy and 3.5-995 Gy for the film with highest (OSL1), medium (OSL2) and lowest (OSL3) sensitivity, respectively. Doses per pulse ranged from 1 to 10 Gy and stability with PRF was tested from 1 to 245 Hz for all films. Reference doses were assessed using alanine pellets, either via simultaneous irradiations, when the expected dose was within the optimal dose range of the alanine pellet, or via extrapolation.
Results: Excellent linearity with dose (R^2>0.999) was observed up to 14 Gy, 150 Gy and 250 Gy for OSL1, OSL2 and OSL3, respectively. Digital saturation, due to the scanner sensitivity setting, occurred at 31Gy, 285 Gy and 680 Gy.
All films showed great linearity (R^2>0.998) with doses per pulse up to the maximal 10 Gy. All films showed good stability with PRF, with a maximal deviation of 4% from the signal measured when delivering pulses at 1 Hz.
Conclusions: The OSL system showed promising properties for a reference dosimetric system in UHDR. It is linear with dose within the dose range used in clinical routine, linear with dose per pulse and stable with PRF, which are important parameters under study in the radiobiology on the FLASH-effect.
This work is part of the 18HLT04 UHDpulse project which received funding from the EMPIR programme. The first author is funded via the young potential PhD grant from SCK CEN.

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EVALUATION OF THE IVISCAN DETECTOR FOR DOSIMETRIC QUALITY CONTROL AND DOSE MEASUREMENTS FOR CONE BEAM COMPUTED TOMOGRAPHY IN RADIOTHERAPY

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Purpose: Image Guided Radiotherapy (IGRT) based on Cone-Beam CT (CBCT) with collimations up to 400mm is often used for patient's positioning in highly accurate radiotherapy treatments. The litterature shows that for collimations greater than 40mm, the 100mm pencil ionization chamber does not consider a large part of the primary and scattered radiation and several methods have been proposed to overcome this problem, but because of the limitation of the available tools, dosimetric quality controls are rarely performed on these wide collimations. This study introduce a new method and device in order to overcome these limitations and perform accurate dosimetric quality control on CBCT.
Material and methods: Fibermetrix® has developed a measurement method and associated device (IVIscan®: based on a scintillating fiber placed on the couch) allowing to integrate the dose even on wide collimations. The CTDI100, CTDIw and CTDIvol are measured and calculated on a CBCT of a Varian Truebeam linear accelerator. We compared the results between the ionization chamber of 100mm, 300mm and the IVIscan® device for the calculated CTDI100, CTDIW for all the CBCT protocols used in the clinical routine of the radiotherapy center.
Results: IVIscan® detector showed comparable performances to currently used methods with differences of less than 5% compared to the reference calculation methods for CTDIw and CTDIvol.
Conclusion: IVIscan is a easy to use tool and can be used routinely for quality control and dose measurements for radiotherapy CBCT.

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A MACHINE LEARNING CLASSIFICATION APPROACH TO PREDICT RADIOTHERAPEUTIC TOXICITY

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Purpose: Radiotherapy plays an essential role in the treatment of head and neck cancers. Radiation toxicity, which can be experienced by some patients and varying in severity, limits the total dose that can be delivered safely. The aim of this study is to identify patients at risk of radiotherapeutic toxicity using computed tomography (CT) images and radiomic feature based analysis.
Material and methods: Data utilised in this study was obtained from The Cancer Imaging Archives (TCIA) and includes thirty-one head and neck squamous cell carcinoma (HNSCC) patients who received radiotherapy to a total dose of 58-70 Gy. Data contains pre-treatment, mid-treatment and post-treatment CT scans acquired with a 16-slice Siemens scanner in addition to treatment planning characteristics and treatment related toxicities. The target output, radiation toxicity, particularly acute toxicity, is a side effect that occurs during treatment or in the period soon after treatment has ended. This project utilises a 2-dimensional deep convolutional neural network (2D-DCNN) to classify patients at risk of radiotherapy related toxicity and to classify overall toxicity grade. Due to class imbalance in overall toxicity for the target variable [Toxicity = 24, No Toxicity = 7], techniques to handle class imbalance are used to improve the model performance. In addition, CT image features were extracted from multiple CT datasets at various time points to

establish predictive features in the pre-treatment CT datasets. The efficacy of the algorithm in categorisation of patients on the basis of toxicity was determined from the receiver operator characteristic (ROC) area-under the curve (AUC).

Results: In this work, we describe an effective 2D-DCNN to predict overall toxicity and toxicity grade in patients who received radiotherapy for HNSCC. The implications of this research and methodology will be presented.

Conclusions: The study demonstrates if 2D-DCNNs can classify patients at risk of toxicity and differences in features extracted from multiple CT datasets may be predictive of developing toxicity and overall toxicity grade related to radiotherapy. Further work is required to test the robustness of the model on a larger external patient cohort.

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APPLICATION OF A NEW FULLY AUTOMATED PLANNING SYSTEM FOR IMRT AND VMAT BREAST IRRADIATION

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Purpose: In this study, a novel system for fully automated lexicographic-based generation of deliverable plans was used, for the first time, to generate IMRT and VMAT whole breast (WB) plans.

Materials and methods: The mCycle system, implemented in Monaco TPS 5.59.3 (not yet commercially available), was used to generate left WB plans (40.05Gy in 15 fractions). A wish-list, based on clinical institution protocol, drove the lexicographic multi-criterial optimization.

Three techniques were developed by establishing constraints and objectives with their priorities: IMRT with two 6MV tangential fields with patient-specific angles; VMAT1 with one 6MV partial arc (295°/165° angles) and VMAT2 with two "tangential" 6MV partial arcs (60° wide). The three techniques were used to automatically generate IMRT, VMAT1 and VMAT2 plans of 25 patients treated in deep inspiration breath hold.

Plan quality was scored by evaluating the achievements of clinical objectives: PTV (V95%>95%, V105%<10%), heart (Dmean<2.5Gy, V2Gy<30%, V10Gy<5%), contralateral breast (Dmean<1.5Gy) and ipsilateral lung (V18Gy<15%), and by the visual inspection of an experienced Radiation Oncologist.

IMRT, VMAT1 and VMAT2 plans deliverability was evaluated by pre-treatment verification of 18 plans for six arbitrarily selected patients.

Results: No manual adjustment of the automatically generated plans was applied, except a dose rescaling, if necessary. Clinical dose objectives for PTV were achieved for all patients except one case where V95% was 94.5% in VMAT1 plan. In one challenging patient only, heart constraints were not respected in IMRT, VMAT1 and VMAT2 plans while contralateral breast constraints were not met in VMAT1 and VMAT2 plans. For six patients ipsilateral lung constraint was fulfilled only in VMAT1 and VMAT2 plans but not in IMRT plans. After physician's review, 22, 23 and 24 plans were considered clinically acceptable for IMRT, VMAT1 and VMAT2, respectively. VMAT2 was always deemed preferable compared to VMAT1 due to a lower low dose bath.

For all tested plans γ pass rate (global approach; 3%/2mm) was greater than 90% with mean values of 95.6%, 93.2%, 95.0% for IMRT, VMAT1 and VMAT2, respectively.

Conclusion: Automation of planning in breast radiotherapy is expected to have a large impact on workload. Almost all automatically produced plans in this study were judged clinically acceptable, thus demonstrating the possibility of automating a large percentage of WB planning, thus keeping a consistent plans quality. Moreover, the use of automated planning allows to generate multiple plans per patient and selecting the best solution for the specific patient.

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4D DOSE RECONSTRUCTION ON DEEP LEARNING BASED 4D SYNTHETIC CTS GENERATED FROM CONE-BEAM CTS

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Purpose/objective: Deep convolutional neural networks (DCNN) have shown promising results for creating cone-beam CT (CBCT) based synthetic CTs (sCTs) and enabling dose calculations in adaptive proton therapy (APT) workflows. In the thorax, breathing motion can impact dose distributions and motivates the use of time resolved 4D imaging for treatment planning and verification. CBCTs, routinely used for patient alignment, can also be reconstructed in 4D. This enables daily monitoring of patient anatomy and treatment progress with respect to breathing motion.

In this study, a DCNN was utilized to generate 4D-sCTs based on 4D-CBCTs and their suitability for 4D-dose reconstruction was investigated by comparing their dosimetric accuracy to a conventional 4D-CT.

Methods: A dataset with 50 lung cancer patients, treated with proton therapy, was used to train and evaluate a U-net like DCNN to generate 4D-sCTs. The dataset was split into a training- (28 patients), validation- (4) and testing-set (18). 4D-CBCTs were reconstructed into six breathing phases using the MA-ROOSTER reconstruction algorithm. An in-house log-file interpreter was used to split the treatment plans into six subplans containing only spots that were delivered in the respective breathing phases. After recalculating the subplans on the corresponding breathing phases, doses were warped and accumulated on the reference phase (maximum exhale). For the dosimetric evaluation, a same-day 4D-CT, deformed to the 4D-sCT (phase-by-phase), was used as ground-truth image. The dosimetric accuracy was quantified globally (gamma analysis 3%/3mm), locally in the target volume (CTV) and organs-at-risk (lung, heart, esophagus), and in terms of NTCP (radiation pneumonitis, dysphagia, 2-year mortality).

Results: Comparing the accumulated doses between 4D-sCT and 4D-CT resulted in an average gamma pass ratio of 93.7±4.8%. High agreement for target and organ-at-risk doses was observed. The difference in CTV D98 was within ±2% for all patients. Mean dose differences in lung and esophagus did not exceed ±1.5%. In the heart higher differences of up to 4.5% were observed. Also NTCP values showed high agreement. Delta-NTCP values (NTCP-4D-sCT – NTCP-

4D-CT) for all patients were between -0.3% and 0.9% for radiation pneumonitis, between -1.2% and 1% for dysphagia and within ±0.9% for 2-year mortality.
Conclusion: High dosimetric agreement between 4D-sCT and 4D-CT was observed. In the future, deep learning based 4D-sCT can enable daily 4D-dose reconstructions and potentially facilitate adaptive proton therapy workflows in the thorax.

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LOG FILE BASED AUTOMATED PATIENT SPECIFIC QA IN PROTON THERAPY
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Purpose: In radiation therapy, it is crucial to ensure that the treatment dose delivered matches the physician approved planned dose. Uncertainties in the treatment planning system (TPS) dose calculations, machine delivery errors or data corruption might lead to differences between intended and delivered doses. The standard patient specific quality assurance (PSQA) of dose distributions is performed through experimental measurement of individual fields (m-QA). A QA platform has been developed to automatize pre and during treatment PSQA at the Groningen Proton Therapy Center. In this work, we analyzed the potential clinical benefits for years 2020/2021.
Material and methods: The PSQA has been clinically performed for all plans (head and neck, thorax, pediatric, etc.) of 816 patients. The QA platform was used to automatically launch simulations, and to identify and report dosimetric inconsistencies. It uses MCsquare as independent Monte Carlo dose calculation engine. Two workflows are defined inside the automatic plan QA: TPS plan QA and Log plan QA. The former is a secondary dose calculation of the TPS plan, the latter is based on plan reconstruction from delivery log files and subsequent dose calculation. For both workflows a dosimetric analysis is performed by comparing its result to the planned TPS dose by means of gamma analysis (2 mm, 2%). In case of a failed gamma analysis check, the m-QA was performed. In addition, volumetric verification imaging based 3D/4D fraction-wise dose reconstruction and accumulation (DRA) is performed through the entire treatment course. In order to assure the quality of the spot recording and plan reconstruction, a machine QA for delivery log files is performed daily.
Results: The automatic workflow performed a total of 2369 plan evaluations over 23 months, for which gamma analysis checks failed for 3.7% and 2.1% for TPS plan QA and Log plan QA, respectively. All the plans for which one gamma analysis check failed, passed the subsequent standard m-QA. The in-room time for PSQA decreased on average from 95 to 32 min/day. Overall, image verification and DRA lead to replanning in 28% lung, 30% head and neck and 50% esophageal plans.
Conclusions: The implementation on an automated QA platform based on independent Monte Carlo dose re-computation and plan reconstruction of delivery log files lead a substantial decrease of in-room time. Integration with DRA will facilitate the introduction of adaptive proton therapy.

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A COMPARISON OF SPECTRAL ENERGY MODES ACROSS DIFFERENT CT VENDORS
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The purpose of this study was to compare the spectral imaging analyses of different CT vendors with respect to atomic composition using a GAMMEX multi energy CT phantom. For simplicity, only results for effective Z were included in this abstract.
A Gammex multi energy phantom with inserts of clinically relevant materials with known atomic compositions and electron density was scanned on a Siemens SOMATOM Force, GE Revolution CT Apex edition, Philips spectral CT 7500 and Philips IQon(WIP, results not included). Tube voltages used were 100, 120 and 140 kVp for Philips, 80-140 kVp for GE, and 70-Sn150 kVp, 80-140 kVp, 80-Sn150 kVp, 90-Sn150 kVp and 100-Sn150 kVp for Siemens. The phantom consisted of an inner module with 8 inserts and a removable outer module with 5 inserts. Scanning was performed at 10 and 20 mGy CTDI, and images reconstructed using FBP with 3mm slices, or 2,5mm with GE. The phantom was scanned with both modules and only the inner module. Nominal values were calculated using the formula eff $Z = \sqrt[a]{[\sum f*Z^a]}$ where a=2,94. Measurements were done on each vendor's workstation: GE AW server, Siemens Syngo.Via and Philips Intellispace.
All effective Z where within 10% of the theoretical value for all thirteen inserts and all scanners. Intra scanner consistency was high when the noise level was low, with Philips systematically lowest and GE highest. When image noise increased, the intra scanner consistency between different voltages decreased. GE was most consistent between the different noise levels, Philips had small inconsistent variations, while Siemens measured higher values for the lower tube voltage used. The measurements on the inserts with 100 mg/mL calcium (eff-Z=9,6) and 5 mg/mL iodine (eff-Z=10,3) were identical for all kVps for a given scanner, while varying between scanners. For the insert containing iodine GE measurements had the highest accuracy (0,3% offset), with Siemens right below (2,5% offset) and Philips last (7,3% offset). For the insert containing calcium Philips had the most accurate measurements (2,4% offset) with Siemens and GE quite similar (5,8% offset).
The vendors' effective Z accuracy was good but may be dependent on image noise and energy level at acquisition. Differentiation of materials with close effective Z and comparison across scanners should be done with caution, and inters canner variability could affect the interpretation.

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OPTIMIZATION OF MYOCARDIAL PERFUSION IMAGING THROUGH IMAGE QUALITY DESCRIPTORS EVALUATION
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Introduction: Evaluation of imaging data is crucial for the optimization of the myocardial perfusion imaging (MPI). Investigation was performed to characterize conventional and advanced MPI systems through a comprehensive evaluation of

relevant physical parameters: spatial resolution, contrast-to-noise ratio, self-attenuation characteristics of the system and perfusion detection capacity. Work was performed under the International Atomic Energy Agency project CRO6021.

Materials and methods: An anthropomorphic phantom with myocardial insert was imaged using two conventional systems (Siemens Symbia) and one advanced IQ SPECT (Siemens Symbia Intevo Excel). Data acquired were reconstructed using filtered back projection (FBP) and iterative reconstruction (IR) algorithms (Symbia), and advanced iterative reconstruction (AIR) algorithm (IQ SPECT). Corrections for scatter (SC) and attenuation (AC) were applied, where available.

Two patient conditions were simulated: normal and pathological heart. In normal heart simulations the phantom was filled with 99mTc solutions of different activity concentrations to simulate the biodistribution of the radiopharmaceutical in the body. In pathological heart simulations a perfusion defect (PD) insert filled with water was positioned at four different positions.

A comprehensive image quality evaluation was performed using various image quality descriptors: left ventricular (LV) wall thickness, sharpness index, contrast between the LV wall and the inner chamber, contrast of the PD with respect to the LV wall, intrinsic contrast and the net contrast. Overall, image quality for five different systems were evaluated: Symbia-FBP, Symbia-IR, Symbia-IR-SC, IQ-AIR-SC-AC and IQ-AIR.

Results: The spatial resolution and the contrast-to-noise ratio were found to be superior for IQ-AIR-SC-AC. Analysis of IR and FBP data of conventional systems showed improvement of image quality when IR is used. Application of SC on conventional systems increase spatial resolution and constrast-to-noise ratio. Intrinsic contrast values were minimal for IQ-AIR-SC-AC, resulting in a more uniform distribution of the activity on reconstructed images. Other systems overestimate the signal intensity in the anterior position, and underestimate it in the lateral and posterior positions. The lack of the detection capability of MPI systems in the posterior part of the heart for all systems except IQ-AIR-SC-AC were also observed. Net contrast results showed that IQ-AIR-SC-AC and Symbia-IR-SC systems have overall largest net contrast means and higher perfusion detection capability.

Conclusions: Characterization of MPI systems via multiple image quality descriptors obtained using static phantom is prerequisite for successful optimization of the MPI procedures. This can be additionally enhanced through the use of non-standard dynamic phantom, which will be the next step in this investigation.

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RADIATION PROTECTION IN CARDIAC INTERVENTIONS

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Purpose: The aim of this study was to prospectively evaluate the radiation exposure to the first operator, performing cardiac interventions at Sahlgrenska University Hospital in Sweden, for three different radiation protection setups: 1) the Rampart M1128 device (RampartIC, USA) with table mounted lead shields and two additional radiation shielding drapes covering parts of the patient, 2) ceiling and table mounted lead shields and two personal radiation protective aprons covering the patient, 3) ceiling and table mounted lead shields corresponding to the normal radiation protection setup for this hospital. The STARTable (Adept Medical, New Zealand) was also used for all setups (except in six procedures for setup 3).

Material and methods: The accumulated radiation dose was measured using 72 thermoluminiscent dosimeters (DXT-RAD Ringlets TLD-100, ThermoFisher Scientific, USA) attached in a grid pattern outside a personal radiation protective apron, worn by the first operator. The personal dose equivalent, Hp(10), registered by each dosimeter, was analyzed after 1) 34, 2) 38 and 3) 35 cardiac interventions (coronary angiography, PCI, CTO, alcohol septal ablation, aortic valve intervention) and the mean for each setup was extrapolated to 250 procedures per operator and year, estimating an annual personal dose equivalent.

Results: The estimated annual personal dose equivalent and (min-max) to the first operator, measured outside the radiation protective apron, was 0.3 mSv (0.2-0.8), 0.3 mSv (0.1-0.6) and 2.1 mSv (0.7-6.5) for respective setup. The mean kerma-area-product per setup was 23 $Gycm^2$ (1-142), 19 $Gycm^2$ (1-139) and 31 $Gycm^2$ (2-148) respectively.

Conclusions: Both setup 1) and 2) reduced the radiation dose to the first operator, outside the radiation protective apron, compared to the normal setup 3). The operators have a desire to perform cardiac interventions without heavy personal radiation protective aprons. But setup 1) and 2) without personal radiation protective apron entails an increase in the personal dose equivalent, compared with the normal radiation protection setup, used at Sahlgrenska University Hospital, that includes personal radiation protective apron. To confirm this further comparative studies are needed and corresponding measurements on the assistant nurse also needs to be done. Regardless, the study shows that radiation protection on the patient reduces the radiation dose to the operators. The study also showed that the radiation dose varied between the dosimeters in each setup, indicating the difficulty in placement of dosimeters for personal dosimetry, to obtain an accurate radiation dose measurement, essential if personal radiation protection is not to be worn.

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FOETAL DOSIMETRY IN PREGNANT PATIENTS UNDERGOING DIAGNOSTIC AND INTERVENTIONAL RADIOLOGY PROCEDURES: INVESTIGATION OF CLINICAL ROUTINE PRACTICE

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Foetal dosimetry in pregnant patients undergoing diagnostic and interventional radiology procedures: investigation of clinical routine practice.

Purpose: To investigate which methods are used by medical physicists in clinical routine and how they are used to estimate foetal doses in diagnostic and interventional radiology (DIR). Medical physicists are typically involved in foetal dose estimation for DIR procedures including pregnant patients and this is generally limited to situations when the foetus is in the direct beam or foetal dose is

predicted to be above 1 mSv. Different approaches are presented in the scientific literature to estimate the foetal dose. However, some of these methods can be either time consuming or of unknown reliability.

Material and methods: The investigation was done in the framework of EURADOS WG12 Dosimetry in medical imaging, SG2 Patient dosimetry. Firstly, a questionnaire with radiation protection considerations and dosimetry aspects was launched to investigate national regulations, local hospital rules and clinical practice for DIR procedures performed on pregnant or potentially pregnant patients. Then, three cases of computed tomography (CT) examinations on pregnant patients (abdomen, thorax and combined pelvis and abdomen) with different levels of exposure and clinical data availability were chosen from clinical practice and sent to the participants for foetal dose estimation.

Results: More than 120 professionals dealing with pregnant or potentially pregnant patients in DIR procedures answered the questionnaire. Around 48% of the responders indicated that they have national guidelines for female patients of childbearing age, 29% stated that they have internal hospital guidelines and 9% responded that they do not have any guideline. Additionally, considerable differences were found between guidelines. Concerning the estimation of the foetal doses from the 3 clinical CT procedures, all 10 different teams involved in the calculation used more than one estimation method. A total of 10 different methods were used, including 6 different software calculation tools. The foetal doses estimated by the different teams varied up to a factor of 2.5 for the same clinical procedure.

Conclusions: The questionnaire results show a need for clear clinical guidelines for DIR procedures on pregnant or potentially pregnant patients. The large variability of estimated foetal doses as well as the variety of methods used, indicates the need to identify the factors that affect the calculations and give further guidance on the limitations of each method.

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SPINE STEREOTACTIC BODY RADIOTHERAPY UTILIZING BODY-FIX DUAL VACUUM IMMOBILIZATION SYSTEM: INTRAFRACTION MOTION ANALYSIS

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Purpose/objective(s): This study aimed to assess intra-fraction motion using cone beam computed tomography (CBCT) for spine SBRT patients treated using the Body-FIX dual vacuum immobilization device.

Materials and methods: We identified 31 patients (53 treatments) with spinal metastasis treated with Stereotactic Body Radiation Therapy (SBRT) and the Body-FIX immobilization system for thoracic (T) and lumbar (L) spine lesions. SBRT was delivered using a Varian trueBEAM machine with a robotic PerfectPitch table. A total of 102 CBCT scans before and after treatment were recorded to determine the uncertainties. The initial CBCT was registered with the planning CT scan to obtain patient setup errors. A second CBCT was obtained at completion of SBRT, which would provide data on immobilization errors during SBRT. Patient translational and rotational positioning data were recorded to calculate means and standard deviations (SD) for residual setup errors and intrafraction motion.

Results: The initial CBCT verification images acquired after setup, but prior to treatment, illustrate the residual setup error. Mean displacements for the translations in the x (lateral or medial-lateral), y (vertical or anterior-posterior) and z (longitudinal or cranial-caudal) directions were 7.4±6.2, 2.2±3.3 and 4.4±4.3 mm. The corresponding mean angles for the rotations in the x (pitch), y (yaw) and z (roll) directions were 0.6±0.7, 0.8±0.7 and 1.0±0.9 º. The mean time (± SD) between the setup and final post-treatment CBCT verification imaging was 8.5±2 minutes. For the post treatment CBCT images, there were slightly lower mean values of 0.5±0.5, 0.5±0.6 and 0.4±0.3 mm for the translations and 0.1±0.2, 0.2±0.3 and 0.2±0.2 º for the rotations.

Conclusions: These data demonstrate that with the Body-FIX dual-vacuum immobilization system plus the robotic couch and the CBCT, we are capable of localizing the patient, to within 0.9 mm and 0.4 degrees. The SD of all translations was 0.7 mm, yielding a 95% confidence interval of 2.3 mm; so we justify a 2-mm margin for the planning OAR and target volume.

Also small positioning errors in vertical direction after the initial CBCT setup were observed, with 90% occurring within 1.4 mm and 95% within 1.6 mm . Consequently a 1.5 mm margin, which incorporates the residual setup error and intrafraction motion, is now used to generate the planning organ at risk volume (PRV) for the spinal cord.

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SECONDARY CHARGED FRAGMENTS FOR DETECTING INTERNAL CHANGES IN PATIENTS UNDERGOING RADIOTHERAPY WITH CARBON IONS

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Purpose: In comparison to conventional photon radiotherapy, radiotherapy with ions reaches better dose distribution conformity and better sparing of surrounding critical organs. Particularly carbon-ion radiotherapy (CIRT) exhibits physical and biological advantages over proton radiotherapy. However, CIRT can be very sensitive to changes of the internal structure of the irradiated object, compromising the dose delivery. Therefore, it is of great desire to develop strategies capable of detecting such internal changes. This work focuses on a non-invasive monitoring methodology to detect changes in the internal geometry of the irradiated object based on the tracking of secondary charged fragments, which are produced in nuclear interactions between carbon ions and the target nuclei and emerge of the irradiated object.

Materials and methods: In this contribution, a carbon-ion treatment plan with an RBE-weighted dose of 3 Gy(RBE) for a 70-cm^3 tumor volume was designed for a head-sized PMMA phantom used as a surrogate of a patient. Experiments were carried out at the Heidelberg Ion beam Therapy Center (HIT) in Germany. Secondary charged fragments were detected by means of a mini-tracker with a detection area of 2 cm^2 based on the technology of semiconductor pixel Timepix3 detectors. To quantitatively evaluate the performance of the presented detection methodology, an air cavity of 2 mm thickness was inserted in the phantom at different depths along the beam axis to mimic inter-fractional changes: in front, at the proximal edge, in the middle and at the distal edge of the tumor volume.

Results: By comparing secondary fragment emission profiles between irradiations with and without heterogeneities, differences were found to be significant. On average, a significance of at least 3σ was reached for heterogeneities in the tumor volume, whereas in front of it the highest significance of 6σ was obtained. For a tracker consisting of eight-fold detection areas, the significances in the profile perturbations increased by a factor of 3 for all positions of the heterogeneity.
Conclusions: The presented work has demonstrated the efficiency of this sophisticated non-invasive method to detect heterogeneities at different depths with clinical relevance. Therefore, this monitoring method is very attractive to be further investigated in a clinical study.

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SELF-LEARNING BASED IMAGE FEATURES EXTRACTION FOR PROGRESSION FREE SURVIVAL PREDICTION OF HEAD AND NECK CANCER PATIENTS

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Purpose: Head and neck squamous cell carcinoma (HNSCC) can be treated with either radiotherapy and/or surgery with or without systemic treatment. For patients with locally advanced HNSCC, local failure rates are 30-50%. Identifying patients with poor local control before treatment might offer options for more individualized treatment intensification. This work aims to propose a prediction model for progression-free survival (PFS) using clinical parameters and image features extracted from PET/CT images used for radiotherapy treatment planning by the self-learning method.
Material and methods: The HECKTOR 2021 data of 224 oropharyngeal cancer patients who were treated at 5 centers were used. Patient data includes the following candidate clinical predictors: age, gender, HPV status, T-stage, N-stage, TNM-group, chemotherapy (yes or no), PET/CT before treatment and the endpoint PFS.
The PFS prediction pipeline consists of three steps. Firstly, three pyramid autoencoders were trained to extract image features from CT, PET and the combined CT/PET images, respectively. Secondly, the clinical features and all image features were put into two forward feature selection processes, separately. Then, we built a clinical Cox-regression model and an image Cox-regression model using selected features. Finally, one combined Cox-regression model was constructed using the outputs of the clinical model and the image model.
The patients (41) from two centers were used for autoencoder training. The other three centers' patients (183) were applied to build and test models in a 3-fold cross-validation.
Results: The clinical features that were selected for building the clinical models were HPV-status, age and T-stage, because they were the mostly selected in the three folds and have been shown to be predictive for HNC outcomes in larger patient cohorts before. The selected image features were from PET scans. Good C-index values were obtained by both clinical models (0.64, 0.74 and 0.67 for training set and 0.71, 0.60 and 0.73 for testing set of Fold1, 2 and 3, respectively) and image models (0.69, 0.79 and 0.66 for training set and 0.69, 0.64 and 0.76 for testing set of Fold1, 2 and 3, respectively). The combined models achieved highest C-index values in both training sets (0.71, 0.83 and 0.70 of Fold1, 2 and 3, respectively) and testing sets (0.75, 0.66 and 0.77 of Fold1, 2 and 3, respectively).
Conclusions: We proposed a PFS prediction model for HNSCC using self-learning based image feature extraction, which may further improve identifying patients that could benefit from intensifying the treatment.

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COMPARISON OF LSF FROM AN OPTIMISED PLANAR SCINTIGRAPHY TECHNIQUE WITH PET/CT LSF

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Purpose: Prior to 90Y selective internal radiation therapy (SIRT) treatment, planar 99mTc-MAA scintigraphy imaging is used in the estimation of the lung shunt fraction (LSF). A geometric mean technique is used for this calculation. However, the LSF estimate is affected by scatter contributions, patient attenuation and respiratory motion. Previous work at our centre has shown that scatter contributions affecting the LSF accuracy can be accounted for through employment of a scatter energy window correction. While this has been demonstrated to significantly improve the LSF estimation accuracy in phantom and Monte Carlo simulations, the scatter energy window technique is yet to be validated with patient imaging datasets. Post therapeutic estimations of the LSF may be estimated through PET/CT imaging of the positron-emitting component of the administered 90Y. Accordingly, the objective of this study was to compare the optimised planar methodology for LSF estimation to that calculated using post-treatment PET/CT phantom and patient imaging datasets.
Materials and methods: An image quality phantom with spherical inserts was used to determine the recovery coefficients for 90Y PET imaging. Subsequently, an anthropomorphic thorax phantom, with fillable organs, was used to simulate known LSFs using 90Y, in order to quantify the accuracy of PET/CT imaging for 90Y LSF determination. The optimised planar LSF estimation was applied to pre-treatment 99m Tc-MAA scans for a cohort of patients. Following 90Y SIRT treatment of these patients, their LSF was calculated from their 90Y PET/CT patient images.
Results: This is part of an ongoing study. A comparison between the LSF of the optimised planar and that of the PET/CT imaging datasets will be presented, to examine whether the optimised planar method of 99mTc-MAA scintigraphy imaging can accurately predict the LSF estimated from the delivered 90Y.
Conclusions: Our proposed method of LSF estimation with incorporated scatter correction can significantly improve the accuracy of the LSF estimation, and is applicable in any imaging centre. Validation of this optimised method has been achieved through post-treatment 90Y PET/CT imaging. This revised methodology facilitates improved accuracy in the dosimetry estimation and a more optimised prescribed patient therapy dose.

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MULTI-TREATMENT DOSIMETRIC EVALUATION: 90Y-RADIOEMBOLIZATION WITH PREVIOUS MR-GUIDED EXTERNAL BEAM RADIATION THERAPY

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Purpose: With the increasing use of radiation in the treatment of liver tumors by transarterial radioembolization (TARE) and stereotactic body radiation therapy (SBRT), a particular focus should be paid to dosimetric aspects for those patients who have received both therapies. In this study, a dosimetric evaluation was conducted for one patient treated with MR-guided SBRT (MRg-SBRT) followed 90Y-TARE.
Materials and methods: the study retrospectively included a patient treated with MRg-SBRT followed 90Y-TARE between 2019 and 2021. MRg-SBRT treatment consisted of 5 fractions for a total dose of 50 Gy performed on MR-LINAC (MRIdian Linac, Viewray). This hybrid system allows step-and-shoot intensity modulated radiation therapy combined with a 0.35T split superconducting magnet MR that provides online sagittal cine MRI for tumour tracking and beam gating during delivery.
Predictive and post-treatment TARE dosimetry was calculated at the voxel level with MIRD scheme based on 99mTc-MAA-SPECT/CT and 90Y-PET/CT, respectively. 1.5 GBq of 90Y-resin microspheres (SIR-Spheres) were injected. TARE- derived absorbed dose was evaluated by MIM Sure Plan (version 7.1.2, MIM software). The single doses were converted to Biological Effective Dose (BED), using the more recent radiobiological model parameters. Finally, BED-maps of TARE and MRg-SBRT were summed voxel-by-voxel with a deformable registration. Compliance to treatment was evaluated in terms of acute and late liver toxicities.
Results: the mean (± SD) BED to tumor and normal liver (NL) derived by MRg-SBRT was 99.6 (± 11.3) Gy and 17.5 (± 30.9) Gy respectively. Instead, the mean TARE-derived BED (± SD) to tumor and NL was 87.5 (± 30.1) Gy and 34.2 (± 38.0) Gy, respectively. The mean accumulated BED was 210.5 (± 62.9) Gy for tumor volume and 57.5 (± 62.9) Gy for NL. Moreover, the dosimetric parameters useful for predicting liver toxicity, V100Gy and V140Gy for NL, were found to be 17.4% and 9.7%, respectively. No acute or late toxicity was reported. Liver function and damage blood tests at 4 months after the end of treatments were within normal range.
Conclusions: dose evaluation in the patient treated with multiple types of ionizing radiation treatment should always be conducted to assess the patient safety while avoiding liver toxicities, including radioembolization-induced liver disease (REILD). This retrospective analysis showed, even if in a preliminary way, that the combined approach can be feasible from a dosimetric point of view and safe in terms of compliance in carefully selected patients. Future studies are needed to confirm these promising results.

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4D ROBUST EVALUATION OF PROTON PBS TREATMENTS INCLUDING RESPIRATION USING DEFORMABLE IMAGE REGISTRATION

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Purpose: To describe the workflow followed to prepare and evaluate our first lung cancer treatment with proton pencil beam scanning (PBS).
Material and methods: A 4DCT was performed in the simulation to quantify the breathing motion. The radiation oncologist contoured the GTV in every phase of the 4DCT and created the ITV by combining all the GTVs. The CTV (330 cc) was created by adding a 5mm margin. The 4DCT average intensity projection was used for planning. Only back incidences were used, minimizing the effect of breathing. The dosimetry was optimized and evaluated robustly with 5mm of spatial variation and 5% of range uncertainty.
Our TPS is RayStation, whose DIR performance in lung 4DCT has been validated. The plan was calculated in the eight phases of the 4DCT to evaluate tumor coverage and organ involvement. Furthermore, all the phase CTs were deformedly registered to the reference one (50% expiration) and to the average projection. The 4D accumulated dose and all single phases metrics for CTV and OAR were compared among themselves and with the planned 3D dose.
The plan was robustly assessed in the accumulated 4D distribution. To combine spatial robustness with respiration, the CTV was expanded 4mm (squared sum of 3mm for the spatial uncertainty and 3mm for the DIR uncertainty: CTVsp). To combine range uncertainty with respiration, a CTVprox and CTVdist were defined by displacing the CTV in the beams direction. Using 10% uncertainty for lung tissue and 3% for the rest, the module of the displacements were 2mm proximal and 5mm distal.
Treatment was performed on a Hitachi ProBeat-CR PT system. Daily positioning was done using Hitachi CBCT ensuring the reproducibility of the proton path. No action was taken for the interplay effect because of the number of fractions (30) to deliver 60 Gy.
Results: Tumor motion amplitude was 2.7mm (LAT), 4.7mm (AP) and 6.4mm (SI). The coverage V95 of the CTV is over 95% in all the scenarios (single phases, robust 3D and accumulated 4D). OAR constraints do not show significant differences in the accumulated 4D dosimetry with respect to the ground scenario.
The statistics in the combined robust evaluation volume CTVsp is V100 = 85% and V95 = 93.17%. The coverage for CTVprox is V100 = 97% and for CTVdist is V100 = 92.5%.
Conclusion: A method to evaluate the robustness of lung cancer treatments including respiratory motion in PBS proton therapy has been proposed.

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OPTIMIZATION OF AN RF ARRAY FOR CARDIAC MAGNETIC RESONANCE AT 8.5 MHZ

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Purpose: Field-Cycling Imaging (FCI) is a novel MRI technique currently in development at the University of Aberdeen. Unlike in conventional MRI, in FCI the main magnetic field is deliberately varied during the imaging sequence in order to probe the variation of the spin-lattice relaxation time T1 with field strength, which has shown to be a potentially useful diagnostic biomarker.
Our group has constructed a whole body FCI system operating at a maximum field strength of 0.2T and are currently conducting patient trials to identify pathologies where FCI may offer new diagnostic information. This work describes the development of a 6-channel torso array tuned at 8.5 MHz, designed for cardiac imaging using FCI.
Methods and materials: Individual coils, of one to three turns, were wound using litz wire (1600×0.020 mm, Elektrisola Co., Reichshof-Eckenhagen, Germany), with a range of diameters from 160 mm to 220 mm and connected to a feed board which provides: capacitive tuning of the coil to 8.5 MHz; impedance matching via a lattice-balun to a low impedance pre-amplifier (WMA08HA - WanTcom

Inc., Chanhassen, MN, USA); and active and passive protection of the pre-amplifiers during transmission.
The performance of these individual elements were assessed through benchtop measurements of loaded to unloaded Q-factor ratios and inter-coil coupling and imaging experiments to determine their sensitivity at cardiac depth.
Results: Our results show that at 8.5 MHz the optimal approach for array sub-elements are 2-turn, 160 mm coils. Elements with larger numbers of turns demonstrate increased sensitivity but at a penalty of inter-element coupling. Larger diameter elements suffered from poorer Q-factor ratios and proved impractical to incorporate into a larger array.
Based on our results we then constructed a complete receiver as a 6 element, 2-turn, 160 mm antero-posterior array with which we obtained proof of concept FCI short-axis cardiac images from a human volunteer at field strengths ranging from 200 μT to 0.2 T. The SNR obtained from these images was sufficient to derive quantitative T1 information from the left ventricle at each field strength.
Conclusion: We have constructed an RF coil array optimised for low-field imaging and successfully demonstrated field-cycling cardiac imaging in human volunteers for the first time. This paves the way for future research on low field and field-cycling cardiac imaging.

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DOSIMETRIC IMPACT OF BREATHING MOVEMENT COMPENSATION IN RADIOEMBOLIZATION

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Purpose: Selective Internal Radiation Treatment (SIRT) is a local treatment cancer which can be optimized using predictive dosimetry from Tc99m SPECT images. In addition to physical phenomena such as attenuation, scatter or partial volume effects that are, in general, partly corrected, respiratory motion has also been shown to impact the image quality but is never accounted for. The goal of this study is to assess, on real patient data, the dosimetric impact of the breathing movement thanks to a motion compensated reconstruction method.
Material and methods: This study included data from 29 patients for a total of 31 SIRT treatments. For each, dosimetric predictions were performed from two types of reconstructed images: 1) conventional OSEM and 2) motion compensated OSEM [Robert and al., 2021], both including scatter, attenuation and resolution corrections. Doses were estimated with Monte Carlo simulation by assuming that the biodistribution of Tc99m-MAA is the same as Y90 and were obtained for liver, lungs, tumor(s), perfused liver, hepatic reserve, healthy perfused liver and healthy liver. Lung shunt fractions and tumor to non-tumoral liver ratios were also computed. The amplitude of movement was estimated from the extreme phases of the 4D reconstruction.
Results: Globally, no systematic significant differences were observed between absorbed doses estimated from 3D and from 3D compensated reconstructions whatever the volume of interest. The same observation was made for the LSF and the TN ratio. However, for three patients, percentages of tumor absorbed doses were higher than 18% in absolute value and this percentage was superior to 40% for lungs for four patients. Percentages of dose difference between estimates from 3D and 3D compensated reconstructions were close to 0 for tumors which had a volume superior to 122 mL. For others, it depends on patients. The mean 3D amplitude was 8.8 mm for liver and 4.3 mm for tumors available.
Conclusion: Correction of respiratory motion appears to be necessary for a few patients with low-volume or site-specific lesions. The criteria for determining whether or not to correct the respiratory movement remain to be determined.

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UNCERTAINTIES OF A 177LU-DOTATATE DOSIMETRIC WORKFLOW BASED ON A REDUCED NUMBER OF SPECT/CT ACQUISITIONS

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Purpose: Absorbed dose estimation in internal radiation therapy usually requires several SPECT/CT images after each injection that are not always possible to acquire in clinical practice. The goal of this work is to estimate, on real patient data, the uncertainties associated with three simplified dosimetric methods that use only one acquisition instead of several ones.
Material and methods: Uncertainties were computed on two patient cohorts: one of thirteen patients (Lyon, France) and one of seven patients (Strasbourg, France). For the first cohort, three SPECT/CT were acquired at cycle 1 (1H, 24H and 96H/144H) and one after the other cycles at 24H. For the second cohort, three SPECT/CT were available at 6H, 24H and 7D after cycles 1 and 4. Three simplified dosimetric methods were proposed. If the organ dose-rate (ODR) is missing at 24H, it is replaced by the ODR at 24H of the next first cycle scaled to injected activities (M1). When there is only one acquisition, dose estimates were made from the patient's pharmacokinetic parameters at cycle 1 (M2) or from a population average pharmacokinetic parameters (M3). Doses obtained from these three methods were compared to the reference method based on three SPECT/CT. Doses were computed with Monte Carlo simulations and a tri-exponential fit. Percentages of dose difference (PDD) between the simplified and the reference methods were computed for kidneys, liver including tumors, spleen and three surrogates of bone marrow. Cross validation was used for M3.
Results: The median of PDD of M1 was inferior to 3.3% at 24H whatever the volume of interest (VOI) (< 1.0% at 1H/6H and < 2.5% at 96H/7D). For M2, medians of PDD at 24H were -3.7% and 13.6% for left and right kidneys, 1.6% for liver and tumors, 1.9% for spleen and 10.0%, 18.6% and 6.3% for respectively L2 to L4, L1 to L5 and T9 to L5. Medians were lowest for delayed acquisitions as at 96H/7D. All medians PDD were inferior to 7.7% for M3 but these results are conditioned by the homogeneity of population pharmacokinetic parameters.
Conclusion: Uncertainties were estimated for three simplified dosimetric workflows.Those information can allow us to choose the most adapted method according to the number of available acquisitions and patient-specific information such as pharmacokinetic parameters.

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PREDICTIVE PRETHERAPY IN BLOOD AND BONE MARROW DOSIMETRY FOR THYROID CANCER PATIENTS PREPARED WITH RHTSH INJECTION

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Purpose: Radioactive iodine (I-131) is administered for remnant ablation in differentiated thyroid cancer (DTC) post thyroidectomy. Although personalised dosimetry is directed under the Euratom 2013/59, a fixed activity approach is still adopted in the most hospital protocols. This approach does not tailor for optimal absorbed doses nor assess the safety of the administered activity. Tumour biokinetics have been demonstrated to alter over time or with repeated treatments, leading to target cells becoming radio-resistant. Hence, maximising the administered activity for the first therapy, with knowledge of the biokinetics, is advantageous. Dosimetry guidlines have been developed for maximising the remnant dose while ensuring that the dose received to critical organs is not exceeded, reducing the risk of inducing toxicity. These dosimetry protocols include the European Association of Nuclear Medicine (EANM), the Italian Association of Physics in Medicine (AIFM) and the Traino models. Prior to I-131 administration, high thyroid stimulating hormones (TSH) levels must be achieved either by hormone withdrawal or by recombinant human TSH (rhTSH) stimulation, where both have shown to have equivalent results. The later significantly reduces morbidity and patient suffering from hypothyroidism; however, there is scant literature on implementing dosimetry in patients prepared with rhTSH and, hence, the predictive power of pretherapy dosimetry has not been fully demonstrated. This study aimed to investigate the predictive power of pre-therapy dosimetry in DTC patients prepared with rhTSH.
Material and methods: A clinical cohort study at St James's Hospital, Dublin, was carried out using an adapted version of the EANM blood-based dosimetry treatment planning protocol, with the dosimetry models of AIFM and Traino also employed. Maximum tolerable activities (MTA) were estimated by whole-body counting and blood sampling after administration of pre-therapeutic (PT) I-131 tracers (6.1±2.5 MBq). The measurements were repeated during-therapeutic (DT) administration of 3.9±0.2 GBq and compared.
Results: Dosimetry results of 13 patients (5 females, 8 males) suggested there to be a significant difference between PT and DT for whole-body residence time (-7.7±8.1%, p=0.007) but not in the blood sampling (1.13±6.49%, p=0.559). There was no significant difference in the calculated MTA for PT and DT in the three models. The EANM model reported the lowest differences (1.7±4.8%, p=0.241) in the PT and DT comparison.
Conclusion: The study reported strong predictability in the various dosimetry models in our patient cohort. The study suggests that dosimetry is feasible for all patients, irrespective of therapy preparation method.

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IMPLEMENTATION OF A VOXEL-BASED DOSIMETRIC WORKFLOW FOR 177LU-OXODOTREOTIDE IN THE CLINICAL PRACTICE: PRELIMINARY RESULTS

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Purpose: The aim of this work is to present a simplified voxel-based dosimetric protocol developed in our institute for the assessment of absorbed dose (AD) to organs at risk (OARs) in peptide receptor radionuclide therapy (PRRT) with 177Lu-oxodotreotide for the treatment of neuroendocrine tumors.
Material and methods: First, images of a cylindrical phantom filled with 177Lu were acquired and a SPECT calibration factor (CF) for the quantification of patients' images was derived. SPECT/CT images of 3 patients who underwent PRRT with 177Lu were acquired for each cycle and at different time points. Our dosimetric routine requires multiple time points acquisitions in one cycle (6h, 24, 144h post injection) and at least one time point acquisition in the remaining cycles. Reconstruction, quantification and dose calculation were performed using the MIM workstation (version 7.1.2, MIM software, Inc, Cleveland, OH), which allows a voxel-based cumulated activity integration and the Voxel S-Values convolution. Evaluation of the impact of different Time Integrated Activity curves (TIAc) on the AD was also performed.
Results: The CF extracted from the analysis was 2.09±0.11 counts/s/MBq. The mean AD per administered activity per cycle for the OARs was: 1.12±0.28 Gy/GBq [0.72–1.72] for kidneys, 1.06±0.26 Gy/GBq [0.64–1.51] for spleen, and 0.07±0.04 Gy/GBq [0.02– 0.11] for bone marrow. For a specific cycle, the AD calculated with multiple time-points and the AD obtained with the simplified dosimetry method showed relative differences within 3% for kidneys, 7% for bone marrow and 1% for spleen. An increase in the mean AD values was observed using the TIAc extracted from the 4th cycle with respect to the TIAc of the 3rd cycle: mean relative differences were 13% [6-21] for kidneys, 19% [13-32] for bone marrow and 7% [1-12] for spleen. The highest differences were found for the first cycle.
Conclusion: The results for the absorbed dose to OARs are consistent with the literature data and suggest that the dosimetric protocol developed for PRRT with 177Lu-oxodotreotide is reliable and can be integrated in the clinical practice. Further studies with larger patients' cohorts and a multicentric approach are however required in order to establish a standardized dosimetric workflow for Molecular RadioTherapy and to assess the impact of the TIAc on the AD evaluation.

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IMET-MRI – UPDATE ON EUROPEAN PROJECT AIMING AT IMPROVING METROLOGY IN QUANTITATIVE MRI

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Purpose: Magnetic Resonance Imaging (MRI) used in routine clinical practice produces images designed for single use, to be looked at by individual human experts. Although a very powerful tool, it lacks consistency when comparing images acquired on different scanners (e.g., same patient scanned on different systems) or at different

times (e.g., follow-up scans). MRI scanners are capable of producing images which measure physical quantities known as quantitative MRI (qMRI), which can provide additional consistency and clinical specificity but these measures require a metrological foundation. This 3-year, European Metrology Programme for Innovation and Research (EMPIR) supported, international project (http://empir.npl.co.uk/imet-mri/) started in June 2021, aiming to develop test objects, traceable methods, analysis tools, and best practice guidance for various qMRI techniques and demonstrate them in an international multi-site trial.

Material and methods: The project is divided into 6 work packages aimed at improving metrological support for clinical qMRI:

WP1 – Phantom Design and Characterisation
WP2 – Digital Tools and Data
WP3 – Multi-Site Trial
WP4 – Code of Practice and Standards Proposal
WP5 – Impact Maximisation
WP6 – Management and Coordination

At this point in the project, metrologically characterised materials have been produced for assessing qMRI measurands (e.g. NMR relaxivities, fat fraction, iron content, intrinsic diffusivity). Pilot studies at 4 MRI sites have been carried out using qMRI sequences and novel phantom designs have been proposed. Moreover, traceable methods to underpin qMRI measurements and material characterisation have been developed. In parallel to experimental work, the creation of a digital phantoms and simulations of the MRI acquisition process is underway. This models the test materials, objects, and acquisition protocols and will assist in fully quantifying the entire measurement pipeline.

Results: Traceable components for relaxometry, iron content, proton density fat fraction and diffusivity have been produced. The results of MRI tests on the qMRI measurands compare well with other test objects with similar components. Preliminary assessment of phantom design has been carried out.

Conclusions: At this time-point in the project (approximately midway), the consortium are on target for their deliverables. Initial results from the first set of scans across multiple sites has demonstrated promising agreement and suggests that further work establishing acquisition and processing protocols can lead to future standards. The availability of these metrologically traceable qMRI components will assist the adoption of clinical qMRI techniques and have advantages for patient care, clinical trials and the use of Radiomics and Artificial Intelligence in healthcare.

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X-RAY FIELD AREA MEASUREMENT USING A RASPBERRY PI ZERO AND COMPUTER VISION

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Purpose: Digital imaging has supplanted CR imaging as the most common imaging detector modality in Irish Radiology Departments. Surplus CR Cassettes have been repurposed by using phosphor screens to assess X-ray geometric properties. This has traditionally been confined to qualitative beam overspill measurements. This study has applied inexpensive computer hardware and open-source computer vision techniques to quantitatively assess beam shape and area.

Materials and methods: A CR phosphor screen (CS lanex regular) was affixed to the X-ray system detector and produced green light during irradiation. The Raspberry Pi Camera was mounted above the X-ray tube output and high-definition video was acquired during the tomographic irradiation. Environmental and image acquisition parameters were optimised to achieve the highest image spatial and intensity resolution. The CR screen was replaced with an image of a chess board pattern. Video images obtained were used to correct for the camera angulation in setup while also providing an image pixel calibration. K-Means colour clustering was used to define beam area in a user invariant manner. The beam dimensions of a Carestream CS 8100 dental OPG system were measured for a variety of environmental light conditions. These conditions were: dark (minimal environmental light levels), indirect (moderate environmental light levels), and direct (high intensity environmental light levels). Descriptive statistics from each irradiation were then compared with current local quantitative method employing Gafchromic® XR-SP2 film.

Results: A homographic transform utilising chessboard pattern successfully corrected images for perspective and angulation. The chess pattern also functioned as a reference object, leading to accurate pixel calibration. K-means clustering proved to be a useful tool for robust image segmentation of the beam area under all dark and indirect lighting conditions; the beam area was successfully segmented without user interaction. Dark videos provided the most reproducible results. Sampling from multiple frames, the measured beam width (FWHM) was 5.23±0.07 mm, agreeing within the measurement error with width as determined from XR-SP2 film of 5.17mm. The height and area were 123± 0.24 mm and 641±8.76 mm^2 respectively.

Conclusions: The study demonstrates that this inexpensive technology incorporating computer vision techniques can be utilised to provide an automated reproducible quantitative assessment of beam area.

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ADAPTIVE THRESHOLD FOR ACTIVITY QUANTIFICATION WITH PARTIAL VOLUME CORRECTION IN 177LU-DOTA THERAPY

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Purpose: Correction of the Partial Volume Effect (PVE) is an issue of great interest in dosimetry for nuclear medicine with SPECT imaging. Although PVE can be easily characterized and corrected in phantoms with objects of known shape and size, it is not the case in patient treatments. In those, small lesion can be assumed to have spherical geometry, however segmentation techniques to be used are not standardized. In these sense, this works aims to evaluate different segmentation procedures in order to properly estimate lesion quantification in SPECT images, applying the suitable recovery coefficients (RC) improving thus dosimetry in Lu-177 therapy.

Material and methods: A Jaszczak phantom with six spheres (volumes 5-16 cc) was filled with different 177Lu sphere-to-background (SBR) concentration ratios (cold background, 6:1 and 46:1) and acquired on a Siemens Symbia SPECT-CT (Medium-Energy collimator, Epeak=208 keV, Ewindow=20%). This ratios aimed to mimic patient distribution after 177Lu-DOTA therapy, in which tumours are located either outside (having thus an almost cold background) or inside the liver (different ratios regarding its proximity to organs with uptake). Camera calibration was done by means of a planar acquisition of a point source and triple energy window scatter correction. RC parameters were then calculated as the ratio of mean and expected activity concentration in a volume of interest. Different segmentation methods were used to draw this VOI and later compared: a spherical VOI (knowing sphere physical dimension), a fixed threshold (1% and 40% for cold and hot backgrounds), and a new proposed method with an adaptive threshold. The latter were chosen for each SBR and sphere as the

threshold for which measured volume best fitted with the physical one of the sphere.
Results: The standard segmentation method (1% or 40%) yielded regions for which volume and shape did not fit with the real ones. This is especially relevant for the smallest spheres which suffer important PVE and are hardly differentiated from the background. Proposed thresholds specific for each SBR and sphere size (range: 22-98%) provideded RC values that are in agreement to those obtained with the spherical VOI.
Conclusions: A methodology based on adaptive threshold for activity quantification of total activity of the lesions using specific RC values has been presented. It provides a more specific threshold procedure than the general one of using 40%, based only on the previous knowledge of uptake lesion to background ratio and an estimated knowledge of lesion size.

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EXPLAINING THE BEHAVIOUR OF A CONVOLUTIONAL NEURAL NETWORK FOR BREAST DENSITY ASSESSMENT

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Purpose: A typical issue related to the use of Deep Neural Networks for image classification is the lack of transparency in the decision process of the algorithm. There are different qualitative methods for explainability but there is not a standard quantitative method yet. We propose a procedure to evaluate both qualitatively and quantitatively the explanation of a Convolutional Neural Network (CNN) for breast density classification through the grad-CAM algorithm.
Material and methods: We used a previously collected dataset labeled by one radiologist in the four BI-RADS density classes (named A,B,C,D), containing 1662 subjects (6648 mammographic images). We preprocessed the images by removing pectoral muscle and background and performing data augmentation. A resnet CNN was trained on these preprocessed data and evaluated in terms of accuracy, precision and recall. Then we computed the saliency maps with the grad-CAM technique, which highlights the regions of the image the CNN looks at when it performs the classification. Since the breast density classification is intensity-based, it is possible to directly study the Spearman correlation between the mammograms and the saliency maps to at least quantify whether there is a monotonic dependence between the images and their activation maps. We also performed the Kruskal–Wallis and Dunn post-hocs with corrections for multiple comparisons tests to validate our analysis.
Results: The CNN accuracy (A), precision (P) and recall (R) are A=83,1%, P=87,9% and R=80,1%. From the visual inspection of the maps we verified that the area of the image contributing most in the algorithm classification is the denser one, hence the CNN computes the correct features to make its prediction. As expected the Spearman's rank correlation coefficient increases as breast density increases. We found a significant difference among the Spearman ranks for each class with the Kruskal–Wallis. The Dunn test showed a significant difference among A, B and C classes (p value < 0.05) while we obtained a controversial result for the D class, which can be explained with the fact that D class is underrepresented in our dataset.
Conclusions: In this study, we present a method to assess trust in a deep model for breast density classification, by providing both a qualitative and quantitative explanation of the classification algorithm. This approach can be extended to other medical images in the attempt to provide clinicians with reliable and explainable AI-based decision support tools.

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OCCUPATIONAL DOSES DURING MANAGEMENT OF THERAPEUTIC (LU177-DOTATATE) AND DIAGNOSTIC (GA68-DOTATOC) RADIOPHARMACEUTICALS FOR THERANOSTICS

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Introduction: The aim of this study is to estimate extremity, eye lens and effective doses in employees of our Nuclear Medicine Department during the management diagnostic (Ga68-DOTATOC) and therapeutic (Lu177-DOTATATE) radiopharmaceuticals for theranostic purposes.
Material and methods: Extremity dosimetry included 5 thermoluminiscent dosimeters (TLDs) (MTS-N (LiF:Mg,Ti)) per hand, and the eye dosimetry one TLD per eye (MCP-N (LiF:Mg,Cu,P)), both provided and analysed by the Belgian Nuclear Research Centre (SCK CEN). A whole-body Tracerco™ Personal Electronic Dosimeter (PED) recorded real-time readings, located at chest level, below the lead apron when worn. Lu-177-DOTATATE (Luthathera) (7400 MBq/session) is administered by one physician and one nurse, monitored for four sessions. Ga68-DOTATOC (200±54 MBq/session) is injected by one nurse, and three sets of TLDs were used, registering the dose of 4, 5 and 6 sessions (Set 1, 2 and 3, respectively).
Results: From Lu177-DOTATATE, physician's mean finger exposures (non-dominant/dominant) were (mSv±SD): 0.8±0.2 below the lowest detection limit (LDL) of 0.57 mSv, while the nurse received doses below LDL (1.2 mSv) in all fingers. Physician received 67 and 62 µSv to the left and right eye, and the nurse 34 and 73µSv, respectively. Mean effective doses per session wearing and not wearing the lead apron varied from (µSv±SD): 10±7 to 4±3 for the physician, and from 23±18 to 6±4 for the nurse. For Ga68-DOTATOC, mean finger exposures (non-dominant/dominant) for Set 1, 2 and 3 were (mSv±SD): 1.5±1.0/1.2±1.0; 2.7±2.0/0.4±0.2 and 1.8±1.3/0.31±0.03. Eye readings stayed below the LDL (51 µSv) except for the right eye of Set 3 (56 µSv). Mean effective doses per session were (µSv±SD): 2.1±1.1; 0.9±0.2 and 1.9±0.6, an average of 1.6±0.9 µSv/session. Hence, it is estimated that Ga-68 (1 session) will account for 2±1 µSv and Lu-177 (4 session) for 20±4 µSv in a theranostic context.
Conclusion: The lead apron reduces the staff doses when treating the patient with Lu-177, so it is strongly recommended. The estimated doses are below the recommended annual dose limits. Nevertheless, more data is needed to conclude whether these can be exceeded by performing these procedures more frequently.
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QA FOR THE CLINICAL IMPLEMENTATION OF KV INTRA-FRACTION MONITORING USING NOVEL 3D PRINTED PHANTOMS

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Purpose: Intra-fraction prostate motion remains an uncertainty that is typically accounted for, enlarging prostate CTV-PTV margins. Varian TrueBeam v2.5+ have an Auto-Beam-Hold (ABH) system which provides real-time intra-fraction motion monitoring. ABH uses 2D planar kV images to detect implanted fiducial markers throughout treatment. Fiducials are permitted to move within a deviation limit (DL), beyond which the MV treatment delivery is paused. Commissioning of alternative tracking software has been reported in the literature(Ng et.al 2014, TG147 2012) however, detail of the commissioning, accuracy and precision of the ABH system is lacking. The aim of this project was to commission the ABH system. Novel 3D printed phantoms were designed and implemented to this aim and will be presented.

Material and methods: The Ultimaker S5 3D printer was used to print three phantoms; A 3D cylindrical phantom designed to fit within the commercially available 'Quasar' Phantom to assess static and dynamic tracking; A custom 3D pelvis phantom (Giacometti et al 2021) 'ELVIS', water filled with bone-equivalent anatomy to assess tracking in clinical conditions; and a simple block phantom combined with a programmable moving platform designed for daily radiographer QC. All phantoms had gold fiducial markers inserts, as will be used clinically.

The 2D planar kV image field size, dose and image quality were optimised by measuring contrast to noise ratio (CNR) of the fiducials in the ELVIS phantom. The ABH detection accuracy and precision was tested using the Quasar phantom in a single direction, couch translations in 3 directions and when using typical prostate patient trajectories. Daily radiographer QC to test the ABH system was designed and implemented.

Results: A 6x6cm^2 kV imaging field size was optimal based on previous patient's fiducial implants. Set exposure of 110kV/10mAs provided an appropriate balance between CNR values and imaging dose, even when imaging through dense pelvis anatomy.

The QUASAR phantom movement accuracy was 0.48±0.12mm. The couch translations had an average accuracy of 0.02±0.07mm across all axes.

The detection accuracy of the markers was ~66% due to issues detecting fiducials perpendicular to the direction of image acquisition. The accuracy of the MV beam on and off was 100% both for the couch movements and the patient trajectories with a precision of ≤±0.5mm. The daily radiographer QC test correctly demonstrated the operation of the ABH system to ≤1mm within a 3-minute test.

Conclusion: The precision and accuracy of the ABH system has been determined using novel printed phantoms.

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ARTIFICIAL INTELLIGENCE MODELS FOR COVID-19 CLASSIFICATION: RADIOMIC FEATURES AND QUANTITATIVE ANALYSIS OF COMPUTED TOMOGRAPHY IMAGING OF VIRAL PNEUMONIA

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Purpose: To optimize a pipeline for the automatic extraction of biomarkers through the quantitative analysis of CT images implemented during the COVID-19 pandemic crisis and to develop artificial intelligence models for the diagnosis of different types of viral pneumonia.

Material and methods: Chest CT images of 1028 patients with positive swab for SARS-CoV-2 (n=646) and other respiratory viruses (n=382) were segmented automatically for lung extraction. A Gaussian model, based on the histogram distribution of CT numbers describing well-aerated and ill portions, was developed in Python language and applied to calculate Quantitative Metrics (QM, n=20) of Both Lungs (BL) and in four geometrical subdivisions (ventral-dorsal, superior-inferior, n=80). Furthermore, Radiomic Features (RF) of first (RF1, n=18) and second (RF2, n=120) order were extracted from BL using PyRadiomics tools. QM and RF were used to develop 5 Multi-Layer Perceptron classifiers, which differ for the number and typology of metrics, to discriminate images of patients with COVID-19 and non-COVID-19 viral pneumonia. In addition, patient age and sex were considered as additional features in each model. The models (type of metrics, total number of features) were the following: Model1 (QM in BL, 20), Model2 (Model1+QM in lung subdivision, 102), Model3 (RF1 in BL, 20), Model4 (Model3+RF1 in BL, 140) and Model5 (Model2+Model4, 240). A LASSO regression (Least Absolute Shrinkage and Selection Operator) and an hyper-parameters tuning with training-test split of 75/25 were performed to select the relevant features and the best parameters of the network. A final 4-Fold Cross-Validation was used to estimate the performance for all the models.

Results: The performance of the models for COVID-19 diagnosis were in the range 0.75-0.89 as the integral of the receiver operating curves (Area Under the Curve, AUC). The accuracy of the Model1 and Model3, based only on QM or RF1 of BL, increased when the geometrical subdivision of the lung or RF2 were considered (Model2, Model4, Model5).

Best diagnostic performances were associated the Model5, based on all QM and RF, with 32 relevant features and an AUC of 0.89±0.01 after 4-Fold Cross-Validation. The relevant features found to be a subset of both QM and RF, showing the usefulness of different methodological approach of metrics calculation.

Conclusions: A platform for extracting useful quantitative metrics from CT images has been developed and optimized. Five artificial intelligence-based models for classifying patients with COVID-19 and non-COVID-19 viral pneumonia were developed and compared showing overall good diagnostic performance.

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TYPICAL REFERENCE LEVELS FOR CARDIOLOGY, INTERVENTIONAL RADIOLOGY AND NEURORADIOLOGY USING A DOSE TRACKING SYSTEM

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Purpose: This work aims to determine typical values for cardiology, electrophysiology, interventional radiology and neuroradiology procedures diagnostic reference levels (DLRs), as recommended in the European Directive 2013/59/EURATOM, through a radiation dose index monitoring (RDIM) software.

Material and methods: To identify the most frequent fluoroscopically-guided procedures to be addressed in this study, a retrospective analysis over a year was performed by the RDIM software NEXO[DOSE]® (Bracco Injeneering SA, Lausanne). For each of the twelve selected procedures, demographic information and

dosimetric data, such as fluoroscopy time (FT), air-kerma at the interventional radiological point (Ka,r) and kerma-area-product (KAP) were collected.
The 4000 considered studies were carried on by four clinical teams using seven angiographic rooms equipped with two biplane Philips Azurion, two Philips Integris Allura, two GE Innova2100IQ and a Siemens Artis Zeego, respectively. Median values of KAP, FT and Ka,r were evaluated and compared to international DRLs. Three neuroradiological procedures (cerebral aneurysm repair, mechanical thrombectomy for acute ischemic stroke (MT) and cerebral angiography), two electrophysiological procedures (pacemaker and implantable cardioverter-defibrillator (ICD) implant, and transcatheter ablation (TCA)), three cardiological procedures (coronary angiography (CA), percutaneous transluminal coronary angioplasty (PTCA), transcatheter aortic valve implantation (TAVI)) and four interventional radiology procedures (prostatic artery embolization (PAE), transjugular intrahepatic portosystemic shunt (TIPS), transarterial chemoembolization (TACE), varicocele) were considered.
Results: Local reference values were established for MT (n=213, FT:29min, KAP:137Gy•cm2, Ka,r:1128mGy), cerebral angiography (n=409, FT:13min, KAP:97Gy•cm2, Ka,r:891mGy), cerebral aneurysm repair in election (n=50, FT:44min, KAP:163Gy•cm2, Ka,r:2531mGy) and in emergency (n=38, FT:58min, KAP:221Gy•cm2, Ka,r:2779mGy), ICD implants (n=251, FT:6min, KAP:2Gy•cm2), TCA (n=154, FT:16min, KAP:4Gy•cm2), CA (n=1258, FT:4min, KAP:20Gy•cm2), PTCA (n=760, FT:17min, KAP:62Gy•cm2), TAVI (n=92, FT:22min, KAP:120Gy•cm2), PAE (n=111, FT:47min, KAP:366Gy•cm2, Ka,r:2251mGy), TIPS (n=55, FT:19min, KAP:129Gy•cm2, Ka,r:514mGy), TACE (n=108, FT:21min, KAP:157Gy•cm2, Ka,r:807mGy) and varicocele (n=48, FT:12min, KAP:25Gy•cm2, Ka,r:60mGy), respectively.
Conclusions: Typical values for diagnostic and therapeutic procedures were evaluated and are lower than European and national (ISTISAN 20/22) DRLs for almost all the considered procedures, except for cerebral aneurysm repair in emergency. This work suggests that the dose tracking NEXO[DOSE]® software is an indispensable tool for evaluating large amount of data and in any case for optimization of existing procedures.
For successful use of these tools, adequate human resources must be planned for data assessment.

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EVALUATION OF A QUANTITATIVE ANNUAL RISK ASSESSMENT MODEL FOR ESTIMATING RADIATION DOSES TO HOSPITAL STAFF COHORTS WORKING WITH NUCLEAR MEDICINE AND PET-CT PATIENTS

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Purpose: A quantitative risk assessment model was developed to assess the radiation dose levels received by third party staff from Nuclear Medicine and PET-CT patients. This allowed for doses to be estimated for those hospital workers interacting with patients following administration of a radiopharmaceutical. The quantitative data can assist in the assessment of dose monitoring requirements and is helpful in the provision of radiation protection advice and risk information as part of training. Having developed the quantitative risk assessment model to estimate the dose to staff cohorts, the purpose of this work was to evaluate the accuracy of the model through dose monitoring of ward and portering staff.
Material and methods: A multiple component radiopharmaceutical-specific exponential biokinetic model was used as the basis for estimating time-dependent dose rates from nuclear medicine and PET patients, including data such as measured administered activities, excretion fractions and self-attenuation factors. In order to estimate staff doses patient throughput, scanning frequency, ward information, staff occupancy and rostering patterns, in addition to patient interaction patterns for various staff and patient cohorts were examined and accounted for in the risk assessment model. This allows for the estimation of the effective doses received by different staff groups based on their interaction with patients. In order to assess the accuracy of the model, staff groups estimated to receive the highest doses were identified and monitored using electronic personal dosimeters (EPDs) for a number of months, with their data compared to the modelled estimate.
Results: This study will present the model-estimated staff dose data, for years 2016 – 2021, for nursing staff in a range of cancer, surgical, general medical and urology wards and portering staff. Of note, the risk assessment estimated portering staff to receive the highest overall doses of those examined in this study, close to the dose constraint of 0.3mSv/yr. The ward nursing staff from the cancer and surgical wards were estimated to receive the highest doses for 5 out of 6 years examined, albeit doses were <100 μSv/yr. Comparisons between the modelled and measured data will be presented with agreement examined.
Conclusion: A risk assessment template quantifying doses to staff cohorts interacting with nuclear medicine patients has been developed, with its accuracy examined. Annually, such a model can be populated with the breakdown of annual workload including referral sources, to facilitate identifying any groups at risk or workflows that require review.

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RADIOSURGERY OF LARGE METASTASIS TREATED IN TWO STAGES: PRELIMINARY RESULTS OF A RETROSPECTIVE ANALYSIS OF 79 PATIENTS

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Purpose: to retrospectively analyse plans of patients with large brain metastasis (BM) treated with two-sessions stereotactic radiosurgery.
Material and methods: since 2018, 79 patients with large BM (>10 cm^3) have been treated with a two-sessions radiosurgery protocol using a dose prescription within 10 and 13Gy at 50% of the maximum dose distribution and a time interval of 1 month between the two sessions. Plans were elaborated with Gammaplan treatment planning systems and delivered on a Gamma Knife Perfexion unit. MR T1 weighted images, dose distribution and structures were exported to MIM Maestro platform for subsequent analysis. A rigid deformation between MR images of the two sessions was calculated and the two dose distributions of the two plans were linearly summed up on the MR image of the second sessions. The initial tumour volume, its change after the time interval Δt between the two sessions (ΔVol%) and the volume of surrounding healthy tissues receiving 12Gy in the summed dose distribution (V12GyHTacc) were calculated. The volume of treated BM and the presence of edema will be considered and analysed as follow-up parameters at 3, 6, and 12 months after the second session.
Results: the dose prescription was 12Gy to BM in both sessions for 76 patients. Two patients received a dose prescription of 10Gy and

13Gy. Two distinct BM were treated simultaneously in 5 patients using the same prescription of 12 Gy in both sessions. For 33 patients, one or more smaller BM with higher dose prescription were treated during one of the two sessions. The tumour volume at the first stage was (24.7±15.1) cm^3 and the shrinkage ΔVol% resulted in (-32±29)% after a Δt of (31.0±5.7) days. In 9 patients out of 79 (11.4%) the tumour increased volume during the time interval between the two sessions and in one of these cases (1.3%) ΔVol% was greater than 30%. The dose accumulated to the healthy tissues surrounding tumours resulted in V12HTGyacc of (48.6±31.5)cm^3. No acute treatment-related toxicity was recorded between the two sessions.

Conclusions: the current protocol of radiosurgery treatment can be effective in controlling large BM during the two radiosurgery sessions. Further information will come from the analysis of follow-up data together with accumulated dose distribution.

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ORTHOVOLTAGE X-RAY MINIBEAM RADIATION THERAPY AS A COST-EFFECTIVE TREATMENT ALTERNATIVE FOR OCULAR TUMOURS

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Purpose: Radiotherapeutic treatments of ocular tumours are often challenging due to nearby radiosensitive structures (macula, optic nerve, lachrymal gland etc.) and the high doses required to treat radioresistant cancers such as uveal melanomas [1]. Although excellent results can be obtained with advanced techniques such as proton therapy and stereotactic radiosurgery, these modalities are not always accessible to patients (due to high costs or low availability) and side effects in structures like the lens, eye lids or ciliary body remain an issue. Minibeam radiation therapy (MBRT) could represent a promising alternative in this regard.

MBRT is an innovative new treatment approach where the irradiation field is composed of multiple sub-millimetric beamlets, spaced apart by a few millimetres. This creates a so-called spatial fractionation of the dose which in small animals has shown to increase normal tissue sparing while simultaneously providing high tumour control rates [2-4]. Moreover, MBRT with orthovoltage X-rays could be easily implemented at widely available and comparably inexpensive irradiation platforms [4,5]. In this proof-of-concept study, we therefore evaluate orthovoltage X-ray MBRT as a potential, cost-effective alternative for treating ocular tumours.

Material and methods: Monte Carlo simulations were performed with TOPAS [6] to evaluate the dose depositions of collimator-generated orthovoltage X-ray minibeams [4,5] in CT images of human patients. Different irradiation angles and minibeam configurations were considered and the dose distributions of X-ray MBRT and conventional proton therapy were compared.

Results: The preliminary results demonstrate that orthovoltage X-ray minibeams allow to achieve and maintain a high degree of spatial fractionation with peak-to-valley dose ratios (depending on the minibeam configuration) of 10-30 in the centre of the eye and 2-10 in the brain. This suggests that, although proton irradiations generally yielded lower doses in critical structures, an effective target irradiation at a decreased risk for adverse effects may be possible.

Conclusions: Due to the normal tissue sparing potential of spatially fractionated dose distributions, MBRT with orthovoltage X-rays could represent a promising and cost-effective alternative for the treatment of ocular tumours, especially in regions with limited or no access to proton therapy or stereotactic radiosurgery. Biological studies (starting in March) are needed to confirm this.

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EEG POWER SPECTRAL DENSITY MAPS DURING APPLICATION OF NEWTON'S LAWS

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Purpose: Physics education studies have shown that students continue to exhibit many naive conceptions about basic physics ideas and laws even after instruction. For example, after instruction about Newton's laws, many students still believe that in the collision of two objects of different mass, the object of greater mass acts with greater force than the object of smaller mass. A recent fMRI study has shown that even physicists with a PhD still have to suppress their naive ideas in science despite their professional training [1]. The aim of this study was to compare the electrical brain activity of participants who were more or less proficient in applying Newton's laws of motion.

Materials and methods: Participants in this study were 25 adults who were divided into two experimental groups (Newtonians and non-Newtonians) based on results of previously conducted testing on the understanding of Newtonian mechanics. They were solving problems in four experimental conditions. In the first two conditions with an asymmetric situation (e.g., a collision of two objects of different mass), Newtonians and non-Newtonians were expected to give opposite answers, while the remaining two conditions with a symmetric situation (e.g., a collision of two objects of same mass) they were expected to give the same answers. The brain activity of participants was recorded with a 61–channel EEG system with a sampling rate of 200 Hz. The power spectral density (PSD) was derived from the EEG data using the Welch method [2] and data from different electrodes were clustered according to [3].

Results: Non-Newtonians had an increased gamma-band PSD activity in the experimental condition in which they encountered the statement that the forces were equal in an asymmetric situation. This activity implies additional effort in the processing of statements that are incongruent with non-Newtonians' expectations. Newtonians did not show a comparable activity. Overall, Newtonians had stronger PSD activity in alpha-band which could indicate that they were more relaxed while solving tasks with the application of Newton's laws.

Conclusions: The results of this study show that it is possible to determine neural correlates of different reasoning about Newton's

laws in participants that are more or less proficient in Newtonian mechanics.

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MODELING TRANSDERMAL DIFFUSION OF OPTICAL CLEARING AGENTS

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Purpose: The human skin shields the human body from a variety of external factors making it one of the most resilient barriers in nature. On the other hand, there is a growing interest in safe and inexpensive skin optical clearing agents (SOCA) in order to improve the diagnostic and therapeutic approach towards skin diseases. The following criteria should be met for tissue clearing: 1) SOCA should have a refractive index near to that of the skin tissue scatterers (mostly collagen) 2) SOCA should be hyperosmotic and 3) biocompatibility. Regarding the diffusion properties of the skin layers, the stratum corneum (SC) plays the most important role while skin's permeability is affected by agent concentration and application time. There are substances that can diffuse the skin even at low concentration while having the power to impact the skin's permeability as they disseminate. Among the most common SOCAs are Propylene glycol and Oleic acid. In this study, the distribution of the above SOCAs in SC and VE was analysed in silico using finite element analysis method (FEM).

Material and methods: The analysis was carried out with FeBio. The boundary conditions, as well as the governing kinematic, equilibrium, and constitutive equations are as follows:

The governing equation for the problem is the typical mass transfer equation which shows how the concentration of the agent in each layer depends on its diffusivity and loss in between layers. In our work, we ignored partition coefficients effects.

The study of the model focused on the following assumptions:

1) Skin model of a young healthy person, with a stratum corneum thickness ≃14μm and Young's modulus ≃ 70MPa
2) The skin model of an old healthy person, with a stratum thickness ≃ 20μm and Young's modulus ≃ 60MPa.

The thickness of the SC was considered to increase with age.

Results: The study of the results obtained from the execution of the diffusion model showed that:

(i) Propylene glycol needs more time (approximately 20%) to reach the equilibrium in VE
(ii) Propylene glycol diffuses to a minor depth compared to oleic acid (approximately 30% less)

Conclusions: The present study is an approach in simulating how SOCAs diffuse into the different layers of skin (SC and VE).

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THE EURAMED ROCC-N-ROLL PROJECT: ANALYSIS OF STRATEGIC RESEARCH AGENDAS AND RELATED DOCUMENTS IN THE FIELD OF MEDICAL RADIATION PROTECTION AND MEDICAL USE OF RADIONUCLIDES

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Purpose: The EURAMED rocc-n-roll Horizon 2020 project aims to propose a European approach to research and innovation in medical applications of ionising radiation and related radiation protection. EURAMED rocc-n-roll is divided into 7 work packages. The objective of work package 2 is to elaborate the ideas of the European radiation protection research platforms which are not primarily or exclusively dealing with the medical radiation protection field (MELODI, EURADOS, SHARE, ALLIANCE, NERIS), but with radiobiology, radiation dosimetry, social sciences, and humanities, radioecology and preparedness for nuclear and radiological emergencies, in the context of medical applications of ionising radiation and the corresponding radiation protection. Moreover, the ideas and concepts of the SAMIRA and MEDICIS projects are analysed as well as those of regulators regarding the application of ionising radiation in medicine.

Material and methods: Research and radiation protection needs in the clinical disciplines using ionising radiation are currently being analysed. The analysis is based on stakeholder consensus and ongoing activities in the field including the Strategic Research Agendas (SRA) of radiation protection platforms, European Commission health and digitisation programmes, EURATOM-funded projects, as well as SAMIRA and MEDICIS initiatives. To identify and prioritise topics, work is being carried out by panel members representing the communities of platforms and initiatives.

Results: Panels for each Work Package 2 task were formed. Several meetings have been organised for each task to discuss research topics linked to medical radiation protection, identify missing topics linked with medical radiation protection research and create synergies and interlinks with topics of the existing EURAMED SRA and other relevant platforms or stakeholders. Surveys have been conducted to collect relevant information and voting procedures have been organised to prioritise research topics. The results of this effort will be included in reports that are currently being drafted or will be drafted within the next months. Based on these documents as well as additional wide stakeholder input and consultation, EURAMED rocc-n-roll will produce by the end of 2023 an SRA for medical applications of ionising radiation and related radiation protection and a corresponding roadmap.

Conclusions: Research topics that are currently being identified are expected to significantly improve medical applications of ionising radiation and corresponding medical radiation protection and to increase collaboration between the European radiation protection platforms, relevant initiatives, projects, and regulatory authorities.

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TASK-BASED STUDY OF DETECTABILITY FOR DOSE REDUCTION USING DIFFERENT MODEL BASED ITERATIVE RECONSTRUCTION FOR THREE COMPUTED TOMOGRAPHY SYSTEMS

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We aimed to evaluate the dose reduction achievable to obtain the same detectability across computed tomography scanners with

different iterative reconstruction algorithm developed by three manufacturers.
Three CT system with full, partial and advanced model-based iterative-reconstruction (MBIR) were used to scan a phantom at three dose levels: standard dose (13 mGy), reduced dose (9 mGy) and low dose (4 mGy). The study was conducted using a standard kernel across different vendors and raw data were reconstructed using FBP and three IR level (low, medium, high). The noise power spectrum (NPS), the normalized one (nNPS) and the taskbased transfer function (TTF) for one phantom's insert were computed following the method proposed by AAPM-TaskGroup-233. Detectability of small lesion for soft tissue (contrast-task |ΔHU|= 100 and 5 mm diameter) was calculated using non-pre-whitening with eye-filter model observer (NPWE).
The nNPS, NPS and TTF changed differently depending on CT systems. The highest value of detectability was found for Siemens (advanced-MBIR), followed by Philips (full-MBIR) and last GE (partial-MBIR) for the same dose and iterative strength: detectability of GE and Philips were about 40% and 25% lower than Siemens, respectively. For each system, the same detectability of standard dose FBP reconstruction was achieved with lower doses choosing a higher iterative level. For Siemens there was a reduction of 10%, 30% and 50% using an ADMIRE level 1, 3 and 5; for Philips there was a reduction of 40%, 45% and 50% using an IMR level 1, 2 and 3; for GE there was a reduction of 15%, 20% and 30% using an Asir-V level of 30%, 50% and 70%, respectively. Different MBIR algorithms were compared and the possible dose reduction using higher iterative levels was evaluated by a task-based metric.

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OPTIMIZATION OF X-RAY PHASE-CONTRAST MICRO TOMOGRAPHY FOR VIRTUAL HISTOLOGY

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Purpose: We present a method to optimize X-ray Phase-Contrast micro tomography (PhC µCT) images to accompany current histology procedures providing additional morphological information and important feedback by means of 3D virtual histology.
Material and methods: We performed tomographic acquisitions of 3 paraffin-embedded breast tissue samples with a polychromatic synchrotron beam (average energy~24 keV) at the SYRMEP beamline of Elettra, the Italian Synchrotron facility in Trieste. The specimens were provided by the Pathology Unit of the Academic Hospital of Cattinara, Trieste University. A sCMOS detector, coupled with a high numerical optic aperture, was used to adjust the pixel size to 1, 2.5 and 4 µm at different sample-to-detector distances. In X-ray CT there is a commonly poor attenuation contrast among soft tissues. Propagation-based PhC µCT imaging technique and application of phase-retrieval algorithm results in major enhancement of soft tissues contrast sensitivity. Tomographic reconstructions were performed by using a FBP algorithm and post-processed for beam-hardening and ring artifacts corrections. Reconstructions were matched with their corresponding histological images and morphological comparison was made. 3D µCT image data was also explored to include the full volumetric information on the specimens, as in conventional histology only few tissue slices are sampled along their depth, thus potentially missing clinically relevant features.
Results: We found a very good match between the histology and CT images. Thanks to the high spatial resolution offered by PhC µCT, the observed structures are comparable to those seen in conventional histology. Moreover, due to the high SNR, important details of the samples' structural features in the PhC µCT images are enhanced. The stromal tissue, the fibrovascular core and the stromal axis, the epithelium and adipocytes are well identified. These structures can undergo alterations in pathological processes of benign and malignant origin. Recognition of these components could facilitate the work of the pathologist.
Conclusions: PhC µCT offers high contrast sensitivity images for soft tissues with the potential to be used in 3D virtual histology. This technique could add the value of three-dimensionality in the study of breast tissues as it would favor the pathologist conventionally working on bi-dimensional sections of tissue.
A potential outcome of this study is the use of CT to guide the sectioning in conventional histology, to avoid missing important features PhC µCT is nondestructive, therefore, does not interfere with current histology workflows. It also allows for subsequent tissue characterization and additional sample slicing if required.

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MONTE CARLO SIMULATIONS OF X-RAY SLOT-SCANNING PEDIATRIC AND ADULT EXAMINATIONS: COMPARISON WITH IN-PHANTOM THERMOLUMINESCENT DOSIMETRY

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Purpose: the suitability of PCXMC software to evaluate organ and effective doses in examinations with a slot-scanning device is investigated through in-phantom measurements with thermo-luminescent dosimeters (TLDs).
Materials and methods: PCXMC is a widespread Monte Carlo (MC) software for calculating equivalent and effective doses in projection radiography and fluoroscopy. However, its use in examinations with scanning devices is not demonstrated. This study investigates two simulation methods: (1) a single-shot event, selecting field dimensions to include the full acquisition range and entering as input the dose-area-product (DAP) provided by the imaging system; and (2) n simulations with contiguous 0.5mm-high slot beams to cover the acquisition range, each with DAP calculated as (DAP_total/n). Infinite focus-to-skin distance (FSD) is set to avoid beam divergence. Finite FSD is considered for comparison. The kilovoltage peak (kVp) and total filtration provided by the imaging device are entered as input. Pediatric 5-year-old and adult patients are considered, and three X-ray tube velocities, corresponding to different DAPs, are investigated. Experimental measurements are performed with adult and 5-year-old anthropomorphic phantoms, provided with TLDs in different radiosensitive organs. Dosimeters are calibrated in air with a digital radiography system at different energies, selecting source kVps equal to those of the experimental acquisitions with the scanning device. In order to provide a sufficiently high signal and reduce the uncertainties, acquisitions are repeated three times for each setup. Effective dose is calculated using the ICRP-103 method.
Results: Doses simulated with method (1) are on average 2% lower than those obtained with method (2), but differences are not statistically significant (95% confidence interval) for any investigated organ. PCXMC underestimates doses for almost all organs for both pediatric (14 out of 17) and adult (14 out of 16) patients. The

same behavior is observed for each acquisition speed. Differences are statistically significant (95% confidence interval) in 65% and 75% of the cases for pediatric and adult patients, respectively. On average, PCXMC underestimates organ and effective doses of 21% and 25%, respectively, regardless of the patient type and speed level. Differences increase when setting finite FSD in MC simulations.
Conclusions: PCXMC is not developed to simulate examinations with slot-scanning devices. A single simulation with infinite FSD and field dimensions to include the full acquisition range is the best approximation and the least time-consuming choice. For both adult and pediatric patients, a rough estimation of the effective dose can be obtained by applying a 25% correction factor.

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ATTENUATION AND STRUCTURAL PROPERTIES OF BREAST PHANTOMS PRODUCED BY ENHANCED FFF 3D PRINTING TECHNOLOGY AND INKJET PRINTING

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Purpose: This work aims at characterizing and evaluating the suitability for apparatus testing of physical breast phantoms manufactured by means of two technologies: 1)enhanced FFF 3D printing technology developed by Morphé (morphe.cc) and 2) inkjet printer with iodine-doped ink.
Material and methods: Physical breast phantoms were manufactured starting from 3D clinical breast images acquired via dedicated breast CT (BCT) or MRI scanners. They were either 1) 3D printed with FFF technology or 2) by means of inkjet printer. The 3D printed phantoms were made either of one material (PLA) or two materials (PLA + PP). The employed technology permitted to locally tune the density of the material on the basis of the pixel value of the original clinical images. In the solution (2), the breast was printed slice-by-slice on paper by means of iodine-doped ink. The amount of the iodine content was decided on the basis of a previous calibration procedure. For clinical images acquired via BCT, two inkjet made phantoms were produced with two different calibration protocols (Paper1 and Paper2). In order to evaluate the produced phantoms, these were imaged via clinical CT scanner at 80 kV and by means of a prototype BCT scanner. The Hounsfield Units (HU) and the background anatomical noise of the acquired images were evaluated and compared to literature data.
Results: HUs at 80 kV for the mimicked adipose and glandular tissues resulted -113 and 26, respectively, in Paper1 phantom and -98 and 202 in Paper2 phantom, this last slightly higher than theoretical and literature data. In the case of paper phantom made from MRI breast images, HU resulted -78 and -118 for the glandular and adipose substitute regions, respectively. In the case of phantoms manufactured by means of FFF technology, these two values resulted -20 and 182 for the model derived from BCT images and -131 and 45 for the MRI derived models. The analysis of the reproduced anatomical background indicated that the realisms of clinical images have been reproduced.
Conclusions: With the theoretical HU of the adipose and glandular breast tissue at 80 kV of -188 and 13, respectively, both the Paper1 phantom and phantoms produced with enhanced FFF technology have demonstrated to be able to replicate attenuation properties of the breast tissues. In addition, the proposed methods permitted to replicate realistic organ background, fundamental for testing x-ray breast imaging apparatus. Further tests of the materials at mammographic spectra energies are ongoing.

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STABILITY OF RADIOMIC FEATURES TO MULTIPLE-READER SEGMENTATIONS IN CONTRAST-ENHANCED COMPUTED TOMOGRAPHY (CECT) IMAGES OF HEPATOCELLULAR CARCINOMA (HCC)

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Purpose: In a cohort of hepatocellular carcinoma (HCC) patients imaged with contrast-enhanced computed tomography (CECT), we aimed to investigate the inter-reader variability of gross tumour volume (GTV) manual delineations, assess the impact of segmentations on the stability of radiomic features and compare feature stability in the arterial and portal phase.
Methods: Thirty-one HCC patients who underwent a CECT acquisition prior to tumour resection were retrospectively selected. Each lesion was manually and independently segmented by three expert radiologists in both the arterial and portal phase, for a total of 186 segmentations.
For each phase, to assess the agreement among segmentations, we computed the Dice similarity coefficient for each pair of readers. Dice coefficients obtained from the two phases were then compared through the Wilcoxon signed-rank test.
The IBSI-compliant software S-IBEX was employed to preprocess both phases and extract radiomic features. Before feature calculation, a trilinear interpolation to isotropic voxel spacing and a resegmentation in the range [-1000, 400] HU were applied. When required, images were discretized with a fixed bin width of 25 HU. For each lesion, 172 radiomic features, describing morphology, intensity-values and textural characteristics of the GTV, were extracted.
Eventually, the Intraclass Correlation Coefficient was computed to quantify feature stability to different delineations. A cut-off of 0.9 was chosen to discriminate between stable and unstable features.
Results: No significant differences were found between DICE coefficients computed in the arterial and portal phase (p=0.34), which achieved a median value of 0.853 and 0.845, respectively, hence suggesting a high agreement among readers in GTV delineation.
Of the 172 computed features, 101 were stable and 58 were not for both the arterial and portal phase. These concordant results between phases are non-trivial as textural changes, determined by the contrast agent, could influence feature stability. Instead, 4 features were stable solely in the arterial phase and 9 in the portal phase. The morphological feature category was the one with the highest number of unstable features in both phases.
Conclusion: In the context of radiomics, the assessment of feature stability is of paramount importance and is recommended to reduce the initial set of radiomic features and hence build more generalizable models. In this work, we identified a set of radiomic features that are stable to multiple-reader segmentations, in both the arterial and portal phase, and hence could be reliably used to develop predictive and prognostic models for HCC patients.

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EVALUATION OF DIFFERENT ALGORITHMS FOR AUTOMATIC SEGMENTATION OF HEAD-AND-NECK LYMPH NODES ON CT IMAGES

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Purpose: To investigate the performance of head-and-neck (HN) elective nodes (CTVn) auto-segmentation using 4 atlas-based (ABAS) algorithms and one deep learning (DL) solution.
Material and methods: Ten heterogeneous HN patients, having body mass index ranging from 19.9 to 26.7 and 20 other HN patients, were selected for the atlas collection and for testing, respectively. On each of the CT patient data, the lymph node levels CTVn2, CTVn3 and CTVn4 left (L) and right (R) were manually delineated by an expert physician.
Four different ABAS algorithms were investigated: majority voting (MIM) (MIM Software, Cleveland, USA), STAPLE, Patch Fusion (PF) and Random Forest (RF) from ADMIRE v3.36 (Elekta AB; Stockholm, Sweden), and one DL solution: ARTplan-Annotate (ART-plan™, Therapanacea, Paris, France). The DL algorithm was trained with >1000 samples/organ from multiple centers. The algorithms performance was evaluated using dice coefficient (DICE) and 95-percentile Hausdorff distance (HD95%).
Results: MIM (meanDICE:0.59±0.08) had significantly lower DICE ($p<0.035$) for auto-segmentation of CTVn2(R/L) and CTVn3(L) compared to STAPLE (meanDICE:0.66±0.10), and other algorithms. In addition, difference was also significant ($p<0.031$) for auto-segmentation of CTVn4(R) compared to PF (meanDICE:0.69±0.08) and RF (meanDICE:0.69±0.08) algorithms. ARTplan (meanDICE:0.71±0.05) was significantly better than MIM ($p<0.03$) on all the nodes levels. Among other solutions, STAPLE was significantly less performing than RF, PF and ARTplan for at least 3 nodes levels ($p<0.035$). PF DICE were not significantly different compared to RF ($p>0.070$) and ARTplan ($p>0.052$). Between ARTplan and RF, results were not significantly different except for the CTVn3(R/L), where ARTplan was significantly better ($p<0.026$).
Regarding HD95%, again, MIM (meanHD95%:12.25±1.77) was significantly less performing than STAPLE (meanHD95%:10.19±3.02), PF (meanHD95%9.58±2.26), RF (meanHD95%:9.41±2.32) and ARTplan (meanHD95%:8.68±0.93) for at least 3 nodes levels. No significant difference was found between ADMIRE solutions and ARTplan, except for CTVn3(R) where HD95% of ARTplan was significantly better than STAPLE ($p=0.043$), and for HD95% of CTVn4(R) for PF, which was significantly better than RF ($p=0.032$).
A new analysis based on the union of the levels for each side showed an increase in meanDICE of 17% for both PF and RF and 12% for ARTplan solution thus demonstrating less inaccuracies in node level separation for ARTplan.
Conclusion: This study investigated for the first time the ABAS algorithms, PF and RF and the AI solution ARTplan for HN lymph nodes segmentation. Results were comparable for PF and ARTplan, with a higher accuracy for the DL method, in managing the upper and lower limits of the node levels.

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SEGMENTING OF PROSTATE CANCER FROM MULTI-PARAMETER MAGNETIC RESONANCE IMAGES USING DEEP LEARNING

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Background: Prostate cancer is the second most frequent cancer identified in males worldwide, (Johnson et al., 2014) accounting for around 20% of all malignancies in the population (Bleker et al., 2020). Use a high-quality prostate segmentation model from mp-MRI images utilizing transfer learning and data augmentation for prostate cancer.
Method: Three hundred forty-five PCa subjects had mp-MRI examination (Philips Ingenia 3T mp-MRI (Philips medical system)), which will include T2WI (axial) and ADC images, for the purpose of this study. The 3D anisotropic hybrid network that is going to employ for training has been stated previously elsewhere (Liu et al., 2017). This is a 2D-3D hybrid network that both the 2D and 3D segments are equipped with encoders and decoders. The model will be implemented on a fully accessible ML system (TensorFlow, version 1.10, Google BrainTeam) within a system that is going to adapt to take advantage of numerous graphics processing units. As the loss function, a soft Dice similarity coefficient (DSC) loss will be applied. Deep stacked transformation (DST) is the data augmentation approach that will be employed in this case (Taha and Hanbury, 2015). There will be two prostate segmentation methods trained on the dataset, with one approach applying DST augmentation and the other method without employing DST augmentation. Prior to training the model using the anisotropic hybrid network architecture, all training images are resized to a resolution of 1.0 mm3 and the measurements are going to normalize to the range [0, 1] (Sanford et al., 2020).
Results: Prior work by Sanford et al stated that data augmentation improved the generalizability of the models to the unseen domain. Furthermore, the data augmentation and transfer learning (finetuning) approaches may be beneficial in bridging the gap between the research setting and the clinic. The true value of this study is that it will show a method of generalizing a model trained at one centre to multiple independent centres using data augmentation and fine-tuning for further validation.
Conclusion: Substantial interest in semiautomated or fully automated prostate segmentation systems has resulted in multiple academic studies and organized challenges. Deep learning approaches have become the preferred method of automating the process of prostate segmentation. In addition, data augmentation and fine-tuning approaches may improve the quality of prostate segmentation.

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NONINVASIVE OPTICAL MEASUREMENT OF BLOOD FLOW IN LAYERED TISSUES USING TIME-DOMAIN DIFFUSE CORRELATION SPECTROSCOPY

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Diffuse optics is a field of biomedical optics investigating the hemodynamic process below the tissue surface. Diffuse correlation spectroscopy (DCS) is an emerging diffuse optical technique used to quantify blood flow index (BFI) in biological tissue [1]. Traditionally,

a continuous wave laser is used to illuminate near-infrared light to the tissue, resulting a limited sensitivity to deep layers. Blood flow quantification with depth-resolution plays an essential role in studies focused on layered tissues, such as the human head. Recently, the time-domain approach of this technique (TD-DCS) was introduced, which allows measuring the blood flow index (BFI) with photon path-length resolution [2], and provides higher sensitivity to blood flows at deeper layers.

Our study aims to quantify BFI with depth-resolution using the TD-DCS method combined with a novel data processing approach [3]. Our novel approach is based on a summation of a series of exponential components, which models the autocorrelation function of the signal recorded using TD-DCS. Utilizing an appropriate model allows quantifying autocorrelation decay accurately which carries blood flow information.

To implement the TD-DCS technique, we developed a portable instrument equipped with a picosecond pulsed diode laser (LDH-P-C-N-760, PicoQuant), single-photon avalanche diode (SPAD) detectors (PDM, Micro Photon Devices), and time-correlated single photon counting electronics (SPC-130, Becker&Hickl). By characterizing the emitter features, we showed that the employed laser module satisfies conditions of the TD-DCS technique [4]. In our investigation, a series of homogeneous and layered phantoms were examined. The liquid phantoms were built based on a mixture of milk (3.2% fat), distilled water, and black ink, which allows tuning the optical properties. The dynamic properties (scattering particle velocity) of the samples were controlled by adding glycerol to the solution. Then we performed venous-arterial occlusion measurement on the forearm of adult humans. All the measurements were carried out with 1 cm source-detector separations.

The results show a difference in magnitude of the estimated BFI corresponding to the dynamic properties of the sample layers. In this work, we validated the feasibility of depth-resolved BFI quantification using the TD-DCS combined with a novel data analysis approach, which is essential for blood flow monitoring and tomography applications employing the DCS method.

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A DEEP-LEARNING-BASED APPROACH FOR DIRECT ATTENUATION CORRECTION OF BRAIN 18F-FDG PET

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Purpose: Positron Emission Tomography (PET) is a functional imaging technique that plays an important role to diagnose neurodegenerative diseases as significant changes in brain metabolism by using radiolabeled molecules such as 18-FDG. The quality of PET images has improved by acquiring additional structural images that add anatomical information in order to produce less degraded final images. In the last years PET-CT systems have taken hold in nuclear medicine since CT images can provide an accurate correction map for the attenuation of 511keV gamma rays. However, CT-based AC (Attenuation Correction) PET typically increases the dose to the patient; moreover, the intrinsic artifacts of CT images and the spatial inconsistencies related to a possible mismatch in patient positioning are reflected in PET images getting worse their quality. Our work aims to implement a neural network able to generate corrected PET brain images starting from non-corrected ones without necessary to perform CT acquisition.

Materials and methods: The neural network chosen for our purpose consists of UNET architecture trained using transfer learning approach and characterized by an Inception-Resnet v2 as encoder, pre-trained on the specific dataset ImageNet. The dataset includes brain images of 727 patients obtained with FDG-PET and it is split into 638 images for training, 34 for validation and 55 for test. The bias metric is used to check model performance and it is evaluated as the percentage difference between the mean value of specific VOIs on predicted image and the same ones on the corresponding ground truth.

Results: The neural network is very efficient to reconstruct the corrected PET images, starting from not corrected ones. The bias percentage between predicted and original images takes a value within ±3% in the central area that is the more significant for the disease diagnosis; the values increase moving to external zone due to the noise but it has not information about the disease. After all, the bias remaining around 10%, a threshold that allows to still detect the pathology.

Conclusion: This work performs a deep learning approach, based on a large dataset, able to create PET brain images reducing the dose to the patient, making the use of CT irrelevant, and overcoming the artifacts related to CT scan. It represents an innovation in that it uses transfer learning approach without the creation of synthetic CT. In addition, it has high performance also in pediatric patients that need to be safeguarded in terms of dose.

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IS PHOTON-COUNTING CT MORE QUANTITATIVE?

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Purpose: Recently, new generation CT scanners equipped with photon-counting (PC) detectors reached the clinics. Photon counting technology is inherently different from energy integrated detectors used with earlier generation scanners. PC detectors offer the advantage of smaller pixel size while eliminating electronic noise and spectral separation of a signal is naturally controlled with a set of user-defined thresholds. Computation of virtual monochromatic (VM) images and iodine quantification (IQ) within the patient are strongly dependent on the quality of spectral data. Given the improved spectral sensitivity of PCDs, we tested the performance of PC-CT against dual-energy CT (DE-CT) in estimating VM and IQ data under various external conditions.

Materials and methods: Comercial Gammex phantom with a set of iodine and tissue-equivalent inserts was used. The most relevant patient-specific factors such as patient size and positioning were simulated by adding external tissue-equivalent plastic rings and purposely offsetting the phantom from scanner isocentre. Scans of each size-position combination were obtained under clinically relevant quality reference mAs as well as the dose below and above it (low and high dose scans). An identical procedure was repeated on the DE Siemens Flash scanner and new PC Siemens Naeotom Alpha scanner using the same reconstruction parameters. The lesser influence of the reconstruction approach compared to patient-related factors was minimized by matching reconstruction kernels between PC-CT and DE-CT. The 3 sizes × 3 dose levels × 2 positions

× 2 scanner types resulted in 32 total scans involving 10 different materials for cross-comparison.
Results: The accuracy of obtained HUs for VM images at 70 keV was measured against ground truth values for each of phantom inserts. The maximum relative error in the large phantom was 12% for PC-CT and 49% for DE-CT. The gap becomes even more significant for low and high-dose scans, 21% and 274% respectively. Precision, estimated as the standard deviation of HUs for low, medium, and high dose scan of the large phantom, averaged over 10 different materials was 3.2 and 153.4 in favor of PC-CT. A similar procedure was completed for iodine concentrations of 2, 5, and 15 mGy.
Conclusions: Naeotom scanner showed improved robustness to patient-specific parameters such as size, position, and dose when estimating iodine concentrations and VM HUs than Flash scanner.

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ASSESSING THE EYE LENS DOSE IN INTERVENTIONAL RADIOLOGY: A PHANTOM STUDY FOR VALIDATION OF MONTE CARLO SIMULATIONS

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Purpose: The decrease of the eye lens equivalent dose limit for professional exposure from 150 to 20 mSv/year can be significant for medical staff involved in interventional procedures.
Eye lens dose assessment in interventional procedures is difficult to be carried out because of large variability.
Monte Carlo simulations allow to study the influence of several parameters on first surgeon eye lens exposure during an interventional procedure.
This work, performed in the framework of a research project funded by Italian "National Institute for Insurance against Accidents at Work" (INAIL), complements the eye lens dose assessment performed by using dosemeters.
Measurement on a phantom will also be performed in order to validate Monte Carlo simulation results in a specific operational condition in interventional suite.
Material and methods: Monte Carlo simulation code chosen in this study is GEANT4.
The irradiation scenery is made up by an angiographic system with undercouch tube and surgical table. A water volume placed on it represents the patient. Only the head of MIRD phantom has been considered to represent the surgeon at the moment. The first surgeon head is placed near the patient, according to more different operator heights. A small volume representing the eye lens has been added inside the eye. The x-ray tube energy spectrum is simulated with representative working parameters (80kV, 3.5 mm Al and 0.1 mm Cu, 48.8 keV mean energy beam). Also the image intensifier has been simulated to understand better its shielding effect.
A KAP-meter has been designed in order to normalize eye lens dose to the number of primary particles simulated.
A first study has been carried out in order to evaluate the influence of surgeon positions and different heights on eye lens dose, with and without protective devices.
Phantom simulation is going to be performed with the anthropomorphic CIRS ATOM, in typical working positions and with most employed protocols.
Results: Surgeon different heights affect the eye lens dose: shorter operators result to be subjected to higher eye lens doses because of the small distance from scattered radiation source. Anti-x goggles effectiveness depends on the design, because scattered radiation can slip through the gap created between cheek and eyewear for some models. Correlation between eye lens dose and dosimeter measurement has been investigated by phantom simulation.
Conclusion: Considering the intrinsic variability of interventional procedures, phantom and Monte Carlo simulations can supply important information on the different parameters influencing medical staff exposure.

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CLINICAL SEQUENCES VALIDATION IN QUANTITATIVE MRI

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Purpose: In MRI clinical practice, quantitative parameters evaluation typically relies on the use of specific commercial sequences and post-processing integrated software, provided by MR scanner vendors. To ensure quantitative data reliability, quality assurance in qMRI (through the implementation of specific protocols) is essential, as recommended by international societies and metrology institutes programs. Relaxation time T1, apparent diffusion coefficient (ADC) and apparent diffusion kurtosis (Kapp) are some of the parameters of clinical interest that can be evaluated through quantitative qMRI techniques. This study focuses on the validation of clinical sequences quantitative maps used for T1, ADC and Kapp assessment with a specifically developed QC protocol for both 1.5 T and 3 T MR scanners.
Materials and methods: Two types of sequences were employed in the acquisition protocol during the same measurement session, in order to remove phantom temperature dependency. The first type ("gold standard") is based on inversion recovery sequence for T1 estimation and on a standard diffusion weighted imaging (DWI) sequence with multiple b values and multiple diffusion gradient directions for ADC and Kapp assessment. The second type includes the commercial acquisition and integrated post-processing software, used for T1 and ADC and Kapp clinical mapping. For T1 mapping, a spherical plexiglass phantom (14 cm diameter), filled with a NiCl2–doped water (1mM/l) and a commercial Agarose gel phantom were used; for DWI parameters mapping, a prototype phantom (developed within the collaboration between CIRS and University of Michigan), containing two different sets of samples (one for ADC and the other for Kapp), was used. Clinical sequences validation was performed comparing quantitative data calculated with "gold standard" sequences (through signal fitting) with those obtained with clinical sequences.
Results: Relative differences between "gold standard" sequence and clinical sequence resulted to be about 1% for T1, in the range 1-6% for ADC (with higher deviations associated with ADC with lower values) and in the range 1-5% for Kapp, for both scanners.
Conclusions: The results obtained in this study allowed to validate sequences used for T1, ADC and Kapp quantification and to assess relative accuracies through quality assurance protocol, with dedicated acquisition sequences and phantoms. This is particularly significant due to the increased number of qMRI clinical applications and implementation of related commercial packages on MRI scanners.

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AMBULATORY NIRS AND BP MEASUREMENTS DURING ACTIVE WALKING: HEMODYNAMIC CHARACTERISTICS OF A NEW CLINICAL TEST FOR SYNCOPE AND FALLS ASSESSMENT IN HEALTHY CONTROLS

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Purpose: Unexplained falls and syncope are common causes of injury and hospitalization in older adults. While an active stand (AS) test assesses the neurocardiovascular response to standing, many falls occur during walking. Here we aimed to investigate the hemodynamic characteristics of a novel active walk (AW) test and compared it to the traditional active stand (AS) test in young healthy individuals controls.

Methods: A group of healthy young community dwelling participants were recruited for the study. Each participant underwent an AS (5 minutes supine, 3 minutes stand) and an AW (5 minutes supine, 3 minutes walking). Continuous beat-to-beat blood pressure (BP), heart rate (HR), and cerebral oxygenation (TSI, O2Hb, HHb) was measured using volume clamp approach and near-infrared spectroscopy (NIRS) respectively. Standardized transient and steady-state features were extracted to characterise physiological signals (i.e. nadir, overshoot, recovery rate, steady-state). Paired tests (t-test and non-parametric equivalents) and mixed effects models were used to assess differences in responses between tests. A p-value <0.05 was assumed significant.

Results: Data from 17 young healthy participants was collected(mean±sd age 22.8±1.09 years). A higher maximum HR was found during AW than AS (57.3 (49.6 – 63.1) vs. 35.7 (29.8 – 38.6) bpm, p = 0.0015). Mean SBP was higher during the AW in the early (-0.89 (IQR: -7.63-4.41) vs. 12.3 (IQR: 5.8-30.0), p < 0.0026), mid (2.2 (IQR: -4.6-5.2) vs. 19.0 (IQR: 10.8 - 21.1), p = 0.0015), and late steady-state interval (-5.2 (IQR: -10.0-4.6 vs. 15.2 (IQR: 10.6 - 26.7), p = 0.00012). Controlling for gender and BMI, AW's had a lower nadir TSI (t(23) = -2.62, p = 0.015), i.e. a 1.73%±0.66 (S.E.) decrease, and a higher HR, increasing it throughout all three intervals (p < 0.001) by 25.7 bpm±6.6, 16.5bpm±5.6 and 15.5bpm±5.4 respectively. CO was significantly increased during the AW, representing an increase of 87%±19.0 (t(22) = 4.62, p < 0.001), 86%±20.4 (t(21) = 4.22, p < 0.001) and 69%±1 (t(20) = 4.03, p < 0.001) in the early, mid and late steady-state intervals respectively.

Conclusions: The underlying cardiovascular mechanisms governing BP control during a postural change followed by walking differs from when it is followed by standing. During walking BP regulation is cardiac output dominated, while during active standing vasoconstriction dominates. This may have significant implications for unexplained falls and syncope are managed during these different activities.

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BERT NLP MODEL FOR MULTICLASS CLASSIFICATION OF RADIOLOGY REPORTS

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Purpose: One of the challenges in cancer research is to extract useful data from large databases. Diagnosis, treatment, interim assessment, and follow-up information of cancer patients are recorded electronically in hospital information systems. Most of this information is stored as free text under clinical evaluations, treatment plans, pathology, and radiology reports. In our institution, all cancer radiology reports of the thoracic region (lung, esophageal, stomach, cancers of intrathoracic organs) are stored under thoracic disease management group (TDMG). When handling such dataset, it is imperative to classify reports according to different cancers. In this study, we have used a pre-trained BERT model for classification of TDMG reports into lung, esophageal and other cancer reports.

Material and methods: Study was approved by the institutional ethics committee as retrospective study with waiver of consent. 3902 reports radiology reports of TDMG were used. This data consisted of lung(75%), esophageal(13.5%) and other cancer(12.05%) reports of chest region. Other cancer reports included cancers of respiratory, intrathoracic organs and stomach. Reports were anonymized and cleaned using a Python script. These reports were annotated, as lung carcinoma(class1), esophageal cancer(class2) or other cancer(class0) reports, independently by 2 experts. We performed a random train–test split(70:30) of the corpus. Training set was used to retrain a pre-trained BERT model (Devlin et al) from TensorFlow. The model was validated using 639 radiology reports from MIMIC-III Clinical Database version1.4 and existing ICD9 tags in the database were used for annotation. This dataset had 57.72%, 14.15% and 28.13% reports for classes 1, 2 and 0 respectively. Precision and sensitivity were calculated for test and validation sets. Area under receiver operating curve (AUROC) and area under precision-recall curve (AUPRC) were determined.

Result: Test overall precision and sensitivity were 0.95 and 0.92; 0.68 and 0.58 on validation. Test AUROC for class 1, 2 and 0 were 0.98, 0.99 and 0.97 and AUPRC were 0.99, 0.99 and 0.96 respectively. Validation AUROC for class 1, 2 and 0 were 0.73, 0.95 and 0.62 and AUPRC were 0.73, 0.71 and 0.35 respectively.

Conclusion: Our study shows that the pre-trained BERT model performs well for classification of lung and esophageal cancer reports but performs poorly for classification of other chest region cancer reports. One of the reasons could be that reports in MIMIC dataset are quite different from the Indian training corpus and also due to imbalanced nature of training dataset or the variety of cancer reports in class 0.

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RE-EVALUATION OF BEAM ENERGY AND FIELD SIZE LIMITS FOR CLINICAL PROTON BEAM THERAPY (PBT) AND RELATED PBT SYSTEM REQUIREMENTS

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Purpose: Proton beam therapy (PBT) is an increasingly well-established radiotherapy modality with more than 100 facilities currently in operation worldwide and many more under development. However, the large financial investment required to build a new PBT facility, even for compact single-room systems, hampers more widespread adoption of this technology thus limiting access to cancer patients who may benefit. The purpose of this study

is to re-evaluate the technical requirements for clinical PBT systems and to suggest potential solutions for equipment cost-savings.
Material and methods: Since the 1990s the design of most clinical PBT systems has been based on a similar set of technical requirements that are generally recognized by the PBT community. This study challenges those requirements and attempts to re-establish a new baseline by examining: (a) the most relevant tumor/target locations for proton irradiation; (b) treatment planning techniques used for these indications; (c) related proton beam field parameters.
Results: Initial investigation suggests that a maximum proton beam energy between 150 and 180 MeV is sufficient to treat a large fraction of indications eligible for PBT. Novel approaches to treatment planning and delivery may increase the number of indications that may be treated with reduced system requirements.
Conclusions: System design concepts were established to transform a reduction in technical requirements for clinical application into equipment cost-savings. These design concepts may enable further democratization of PBT for eligible cancer patients.

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COMPARISON OF MICROBEAM RADIOTHERAPY TO CLINICAL TREATMENT PLANS BASED ON THE EQUIVALENT UNIFORM DOSE

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Purpose: Microbeam radiotherapy (MRT) is a novel treatment approach with kV x-rays, which is promising, e.g., for inoperable or highly aggressive tumors. Preclinical studies have shown that the micrometer-scaled spatial dose fractionation spares healthy tissue without compromising tumor control compared to conventional radiotherapy. Prior to clinical trials, treatment planning studies need to identify suitable clinical use cases. However, it is unclear how the effect of spatially highly modulated MRT doses compares to that of conventional clinical doses. We compare MRT and clinical dose distributions based on cell survival in a microbeam treatment planning study.
Material and methods: We have implemented the calculation of the equivalent uniform dose (EUD) in each CT voxel into hybridDC, a dose calculation algorithm combining the accuracy of Monte Carlo simulations for the photon transport and the efficiency of kernel-based calculations for the dose deposition by secondary electrons. The EUD is based on the linear-quadratic model (LQM) and assigns a spatially fractionated dose distribution to a homogeneous dose leading to the same radiobiological effect. Using the LQM, the MRT and clinical dose distributions were further converted into the equivalent dose of 2 Gy fractions (EQD2) to compare different temporal fractionation schemes.
Results: We performed MRT planning on different tumor sites such as glioblastoma, lung cancer, breast cancer, and sarcoma metastases in the bone and brain. With several fields that were conformal to the respective clinical planning target volume, the MRT treatment plans yielded clinically acceptable target coverage and sparing of organs at risk. However, the MRT plans resulted in a more heterogeneous target dose (EUD) than the clinical plans, visible in dose distributions and dose-volume histograms. Different microbeam alignment geometries such as interlaced MRT and cross-firing MRT were compared.
Conclusions: The developed framework allows microbeam treatment planning for clinical cases and the comparison of MRT plans with clinical treatment plans. Next steps should include dose optimization possibilities for an improved dose conformality and beam intensity weightings. Moreover, the EUD needs to be verified with in-vivo experiments for MRT.

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OPTIMIZATION OF PATIENT DOSE EXPOSURE FOR DIGITAL RADIOGRAPHY SYSTEMS USING AN ANTHROPOMORPHIC PHANTOM

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Purpose: to perform the optimization and harmonization of digital radiographic protocols of the pelvis, hips and lumbar spine of a standard patient using a realistic, tissue equivalent anthropomorphic phantom.
Material and methods: Eight digital radiography equipment from four different manufacturers were included in this study. A male pelvis anthropomorphic phantom (CIRS, USA) was used to simulate a standard patient under AP pelvic, hips and lumbar-spine diagnostic X-ray imaging. Image were acquired using the three different protocol with fixed exposure (80 kV, 10 mAs), AEC mode with different tube voltages from 65 to 90 kV at 5 kV step interval and filtration. Dose area product (DAP) was collected from each system and entrance surface dose (ESD) was measured with a solid-state dose detector positioned at the phantom's surface. Image quality was evaluated using both visual grading analysis and physical measurement (i.e. contrast-to-noise ratio). A comparison of objective and subjective evaluations was performed in order to optimize X-ray protocols for each equipment.
Results: Images acquired at the same exposure parameters (80 kV, 10 mAs) displayed a wide range of contrast to noise ratio (from 0.8 to 2) and dose (DAP from 5.9 and 9.1 dGy*cm2) for the different digital X-ray equipment in use. Large reductions in ESD and DAP were achieved while increasing kV from standard protocol. However, percentage change in ESD and DAP varied significantly for each unit. Based on the relationship between measured CNR and ESD for each exposure setting in association with images rated acceptable by radiologists, a set of tube voltage values for producing image of adequate diagnostic quality were identified.
Conclusions: An anthropomorphic phantom was successfully used in patient dose optimization of digital radiographic examinations of the pelvis, hips and lumbar-spine. The results indicated that optimization should be individualized for each equipment due to difference in their performances. In this study, the optimization strategy involved physical parameters (CNR, ESD, DAP) assessment validated by observer-based performance.

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DAILY EFFECT OF IONIZING RADIATION ON MICROCIRCULATION: FIRST EXPERIMENTAL EVIDENCE FROM A HEAD AND NECK CLINICAL STUDY

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Objective: The detrimental effect of ionizing radiation on microcirculation impacts the development of a proper inflammatory response. To model the radiation-induced damage on capillaries, we assessed a set of functional/morphological parameters using sublingual microscopy (SM) on a cohort of head and neck (H&N) cancer patients (pts). Such models will be included in an in-silico model of the vascular microenvironment (already developed) to describe the effects of radiation on the tissue mechanistically.
Materials and methods: H&N pts treated with chemo-radiotherapy underwent a non-invasive investigation of mucosal sites. SM (managed by the patient) records capillary images and provides values for Capillary Density (CD), Capillary Diameter, Capillary Blood Volume (CBV), Red Blood Cell Flow (RBCF), and the erythrocyte Perfused Boundary Region (PBR), a marker for the endothelial glycocalyx barrier properties.
We performed weekly registration during RT treatment unless patients had discomfort due to mucosal alteration. Values were normalized to the baseline measurement (before RT start) for obtaining relative variation with time.
In parallel, we retrieved the average dose to the oral cavity (avgOCD) from the treatment planning system. We scaled it by the number of fractions delivered at the time of the SM measure. Parameter evolution was fit as a function of avgOCD.
Results: We enrolled 15 pts for this preliminary analysis performing 53 measurements:
AvgOCD per fraction ranged between 0.25-2.20 Gy,
AvgOCD at the time of the measures falls between 0 and 53.8 Gy.
For RBCF and CD, a relation with dose was not identified, suggesting a possible limit in the number of patients and an effect that is not immediately manifested.
On the other hand, CBV showed a decreased exponential trend with dose (CBV=100*e^(-0.022avgOCD(t)) and R2=0.25) with a reduction of 50% when OC reached a cumulative dose of 30 Gy. By the end of the treatment, the drop can arrive at 1/4 of the baseline value for some pts. Finally, PBR showed a quadratic trend with dose (R2=0.20); a slow decline (10%) up to 25 Gy to the OC followed by a total recovery by the end of the RT. Parenchymal and vascular endothelial cell injury could explain this reduction in PBR.
Conclusions: Early findings showed a detrimental capillary state after 25-30 Gy of radiation, proving that SM can be used as a non-invasive tool to assess the microvascular health condition and its evolution during radiotherapy. For a better description, the analysis will include a synergistic effect of the chemotherapy in the future.

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MODELLING A NEW APPROACH FOR RADIO ABLATION AFTER RESECTION OF BREAST DUCTAL CARCINOMA IN SITU BASED ON THE BAT 90 MEDICAL DEVICE

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Purpose: BAT-90 (BetaGlue Technologies SpA) is a new medical-device for the treatment of ductal carcinoma in situ (DCIS). BAT-90 is based on the administration of Y-90 β-emitting microspheres, embedded in a bio-compatible matrix. The aim of the work is to implement a Monte Carlo (MC) simulation to evaluate the activity needed to deliver a 20 Gy isodose at a given distance z from the tumour bed, where the BAT-90 layer is located. The MC simulation considers different device thicknesses, tumour bed sizes and two bulk materials (water and adipose tissue). The Poisson and logistic Tumour Control Probability (TCP) models are used to predict the tumour control rate.
Material and methods: The Geant4 simulation toolkit (version 10.5) is used to simulate the transport and interactions of the electrons emitted in the beta decay of Y-90. BAT-90 is simulated as a homogenous cylindrical Y-90 layer placed in the middle of the bulk material, segmented in cubic voxels of 1 mm side for the dose evaluation. Each simulated event consists of one electron from the beta decay of Y-90, isotopically emitted. The dose profile calculated for 107 decays is used to determine the activity needed to provide a 20 Gy isodose at different distances of interest from the tumour bed. The clonogenic cells surving (SF) fraction is estimated, which is the input data for both the Poisson TCP model and the Equivalent Uniform Dose (EUD), used in the logistic TCP model. A comparison with other radiation sources used in partial breast irradiation is performed (electronic brachytherapy, I-125 seeds, Ir-192 HDR brachytherapy).
Results: BAT-90 dose levels are higher in the near-tumour zone and the dose fall of is more rapid than the other brachitherapy sources. In each plane parallel to the tumour bed, the dose is uniform and steeply decreases in correspondence with the edge of the tumour bed. The dose becomes negligible at about 10 mm from the tumour bed, according to the maximum β-particles range. The Poisson TCP decreases as the size of the tumour bed increases and increases for decreasing radio-resistence parameter.
Conclusions: The results of both the Monte Carlo simulation and the theoretical radiobiological model show that BAT-90 represents a feasible therapeutic approach for the irradiation of surgical margins following resection of DCIS via BCS in case of small lesions, similar to those identified by ASTRO/SSO.

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COMPARISON OF THE UNCERTAINTIES FOUND IN DIFFERENT METHODS USED TO CALCULATE THE MTF IN CT FROM IMAGES OF A BAR PHANTOM. A SIMULATION STUDY

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Purpose: A simulation study is presented in this work to compare the uncertainties in the calculation of the modulation transfer function

in CT equipment following two different methods, when a linear bar phantom with periodic patterns of different periods is used.
Material and methods: Images of a bar phantom are created following a procedure that simulates the steps of standard radiological image formation: spatial sampling, blurring and noise addition. The point spread function used in the process has been designed to simulate the blurring found in CT images. The phantom consists of five groups of bars with frequencies ranging between 0.63 and 1.67 1/mm. Two different methods are compared. The first one or variance method (V) obtains the amplitude of the first harmonic of the output signal from the variance of areas inside the phantom image and inside the uniform background. Then the MTF is calculated at the group frequency as the ratio of that amplitude to the amplitude of the input signal first harmonic (Ref. Droege et al.). The second method or direct harmonic method (DH) obtains the first harmonic of the output signal by applying an oversampling method to the phantom image (Ref. A. González et al.).
Results: Relative biasing ranges from 6% to 32% for the estimates of the V method whereas for the DH method it ranges between 1% and 2%. The relative uncertainty for the V and the DH method range from 3.4% to 139% and from 2.3% to 35% respectively.
Conclusion: Regarding accuracy and precision, the DH method is shown to outperform the V method in the range of frequencies studied. This range is also strongly limited by the V method, which can only be applied at frequencies over one third of the cutoff frequency of the system (Ref. Droege). This does not apply to the DH method, as it can be used for MTF calculations at low frequencies too. The results found in this work should have an impact in CT quality control procedures since bar patterns are found in many of the phantoms used for this purpose in CT equipment.
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AUTOMATED FRAMEWORK FOR NON-DESTRUCTIVE EVALUATION OF IMPLANT-ABUTMENT CONNECTION BASED ON MICRO-CT IMAGING: MICROGAP CHARACTERIZATION

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Purpose: To propose an automated micro-CT imaging framework for non-destructive analysis of monolithic implant-supported restorations (MISR) to assess potential risk of failure. Bad surface contacts produce micro-gaps, enabling microorganisms' reservoirs and impairing healthy peri-implant tissues.
Methods: Eight MISR with two zirconia implants were produced and grouped into: A (cylindrical titanium base abutments for the crown) and B (conical titanium base abutment for the prosthesis and cylindrical titanium base abutment for the crown). Sixteen implant-abutment connection specimens were imaged using a micro-CT system (Hamamatsu X-ray tube focus size 20µm, flat-panel pixel size 50µm). To optimise the MISR acquisitions and solve structures overlapping issues, a positioning and centring procedure is created using 2D-orthogonal projections with a single implant or both implants overlapping in the field of view. GPU-boosted reconstruction algorithms generated high quality 3D-stacks reducing ring and misalignment artefacts and distortions due to beam hardening. Automatic self-aligning and segmentation algorithms for 3D-stacks were developed to identify potential micro-gaps. Different geometrical parameters such as contact length of the implant-abutment threads, fitting fraction (quotient of contact thread depth and the sum of implant-abutment threads) and assembly length in the interphase were automatically measured.
Results: Misaligned geometry-related artefacts were successfully removed to obtain 8.11µm voxel size 3D-stacks. Mean and (max,min) values for group A were: contact length of 1314 (1174,1549)µm, fitting fraction of 27% (24%,31%), average gap 61µm. For group B: contact length was 1752 (1701,1784)µm, fitting fraction of 28% (26%,31%) and assembly length of 1044 (1030,1050)µm with no detected gaps. Mathematical models of the implants were generated by volume segmentation, which together with a jawbone can be used as anatomical phantom to test dental imaging systems.
Conclusions: An automated framework for non-destructive analysis of MISR and risk of failure analysis, based on micro-CT imaging, was successfully developed and tested. The self-alignment and post-processing algorithms allowed automatic and faster reconstruction for arbitrary MISR. Automatic accurate detection, measurement, and characterization of the micro-gaps and internal structure was performed. Notable differences were found between both implants' groups: existence of gaps in group A, and greater stability and fixity for group B. The latter has a higher potential success rate due to its long assembly and contact length of both threads. The presented method can be generalised to other implant types or samples.

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CT OPTIMIZATION: COMBINING COMPLIANCE WITH CONTINUAL IMPROVEMENT IN QUALITY AND PATIENT SAFETY

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Purpose: The Belgian Royal Decree of February 2020 on medical exposures (following the 2013/59/EURATOM directive) stipulates that two CT optimization studies are to be performed annually from 2023, with the active participation of a recognized medical physics expert (MPE). Although it may seem like a simple task, identifying, planning and executing meaningful optimization procedures is not always straightforward and is even more difficult to achieve without a dose management system. In this study, the first test optimization activities that were executed in a hospital group since the introduction of this law are presented.
Material and methods: The study was performed on 4 CT scanners (Siemens, Germany) of 3 campuses from the same hospital group. The same MPE is responsible for the services and the scanners are connected to the same dose management system (DOSE, Qaelum, Belgium). This allowed for peer comparison in addition to dose optimization. The process was the following: 1. Evaluate protocol performance and compliance with national diagnostic reference levels (DRLs), 2. Identify protocol or practice deviations when high dose differences occurred between scanners, 3. Perform corrective actions and follow up (feedback from radiologists regarding image quality was considered).
Results: The compliance monitoring provided by the dose management system revealed two protocols that are close or above the national DRLs: a) abdomen, and b) sinus.

a) Abdomen: With a CTDI of 11.4mGy for a single acquisition, one scanner was found to be 1.4mGy above the DRL and 50% higher than the average of the other 3 scanners. The dose differences were mainly attributed to technical factors, most of them related to suboptimal settings (e.g. boosted dose modulation to compensate for lack of contrast, even though was being used). Modifying settings resulted in an average dose reduction of 6.8% while still keeping the radiologists satisfied.
b) Sinus: In the two scanners where this protocol was checked, one used a much higher dose, almost 50% above the national DRL of 4.5mGy. It was discovered that on this scanner the standard protocol was used instead of the low dose one (which uses a Sn filter). Changing the practice led to a dose reduction of 77.8%.

Conclusions: A structured way of executing optimization activities allows the department to be compliant while improving with a focus on both the ALARA principle and maintaining exam quality. An advanced dose management system is an invaluable assistant in this process.

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HYPOXIA-BASED ADAPTIVE TREATMENT PLANNING: THE IMPACT OF THE IMAGE REGISTRATION METHOD

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Purpose: To assess the impact of the method used for image registration on the outcome of a dose painting approach based on FMISO-PET hypoxia.

Materials and methods: Thirty head and neck cancer patients were imaged with FMISO-PET/CT before radiotherapy and the FMISO uptake converted into pO2 values by applying a previously developed function at voxel level. FMISO-PET/CT images were registered to the planning-CT in the treatment planning system RayStation either by rigid (RIR) or deformable (DIR) image registration. HTVs were contoured on the corresponding pO2 maps at 10 mmHg for the deformed (HTV_def) and non-deformed (HTV) case. CTV was segmented into hypoxic target volume (HTV), GTV-HTV and CTV-GTV. A dose escalation strategy consisting of uniform doses applied to the segmented targets aiming at 95% of tumour control probability (TCP) in the CTV was employed.

The impact of the registration method was assessed based on three evaluation levels: I) characterization of the HTVs based on different geometry-related metrics, on the underlying pO2 distribution, and on the corresponding dose boost level. Selected patient cases were further analysed through II) a dosimetric evaluation, based on a gamma index, of the treatment plan differences for HTV and HTV_def; III) a radiobiological evaluation, in terms of TCP values, considering the RIR and DIR dose distributions and their corresponding radiosensitivity maps. TCP was also evaluated for the specific case where the RIR dose distribution was used together with the radiosensitivity of the deformed PET image (assumed to be the actual patient radiosensitivity), to determine the effect of an improper alignment between dose distribution and radiosensitivity map.

Results: Statistically significant differences were found between HTV and HTV_def in terms of volume-based metrics, location and underlying pO2 distribution. Uniform dose prescription levels, theoretically depending both on tumour size and pO2 values, were negligibly different (p=0.12). Treatment plans with uniform dose escalation levels in the boost volumes HTV and HTV_def showed differences on the level 5%/3mm on the gamma analysis. TCP difference in the CTV between RIR and the case when the RIR dose distribution was used with the deformed radiosensitivity map resulted in 0.2±0.7%.

Conclusion: The choice of the registration method of PET-to-planning-CT images impacts on the localization and morphological variation of the hypoxic compartment and corresponding dose distribution but shows to negligibly affect the target control. Thus, in this context, the use of DIR over RIR seems not justifiable.

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A FEASIBILITY STUDY OF DEEP STATED TUMOR TREATMENTS COMBINING FLASH EFFECT AND VERY HIGH ENERGY ELECTRON BEAMS

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Purpose: Over the past decades, technological advances have improved the efficacy of radiation therapy (RT) cancer treatment. Nevertheless, the RT potential is still limited by normal tissue complications. On the other side the specific interactions of charged particles with matter can help in sparing the healthy tissues, while keeping the same target volume coverage. Very High Energy Electron (VHEE) beams have been explored as they have enough energy to reach deep seated tumors. However, the availability of VHEE and other charged particles in the clinic has been hampered by the size, complexity, and ultimately high cost of the beam production system. In this context, the recent developments in the field of compact C-band electron acceleration and FLASH radiotherapy are representing a promising perspective. In this contribution we investigate how recent developments in electron beam therapy could reshape the landscape of deep-seated tumors treatment, presenting the results in few selected cases (prostate, head and neck) and comparing them with what is currently obtained with photon or proton treatments.

Material and methods: We have obtained a VHEE Treatment Planning System combining an accurate Monte Carlo (MC) simulation with a simple modelling of the FLASH effect. The dose maps obtained for a given set of conditions (unit fluence, defined point of access inside the patient body,etc) have been used, as input for an optimisation algorithm capable of defining the beam fluence

in all conditions starting from the treatment prescription of the to the PTV and of the sparing that has to be achieved on the OARs.
Results: The tumor coverage and the dose absorbed by the organs at risk have been analyzed by means of Dose Volume Histograms. The comparison of the achieved results with real IMRT plan and simulation of a proton therapy treatment has been performed. The results show that FLASH therapy with VHEE beams (70-130 MeV) is competitive with standard RT and could allow a better sparing of the healthy tissues.
Conclusions: The results demonstrate that FLASH therapy with VHEE beams of 70-130 MeV could represent a valid alternative to standard RT allowing a better sparing of the healthy tissues. The impact on deep-sated tumor will be discussed also in view of the results obtained when comparing with proton treatments.

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DEVELOPMENT OF A IORT TREATMENT PLANNING SYSTEM USING A GPU-BASED FAST MONTE CARLO

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Purpose: Intra Operative Radiation Therapy (IORT) is a technique that, after the surgical tumor removal, delivers a dose of ionizing radiation (4-12 MeV electrons beam) directly to the surgery bed. During IORT treatments the beam is passively collimated by means of a PMMA hollow tube (applicator) and whenever needed, temporarily beam modifiers (such as the protection disk for breast treatment) are used to protect the healthy tissues surrounding the target from the undesired dose. Today the use of high-intensity pulses of electrons makes IORT the current best candidate for the first implementation of the FLASH effect into the clinic. Currently, the main IORT limitation is the unavailability of a Treatment Planning System (TPS) due to the very limited amount of time available during the surgery (order of 1 minute) to obtain both the new imaging of the surgical field, which has undergone substantial morphological modification and the TPS computation. In this contribution, exploiting the new 3D real-time echographic imaging acquisition provided by the SIT company (Aprilia (LT), Italy), we investigate the efficiency achievable in IORT and IORT-FLASH breast cancer treatment using a GPU-based (Graphics Processing Unit) fast Monte Carlo (MC) called FRED (Fast particle thErapy Dose evaluator) as a tool for treatment planning.
Material and methods: The FRED MC has been developed to allow a fast optimization of the TPS in Particle Therapy while keeping the dose release accuracy typical of an MC tool. This software has been written to run on GPU, so to reduce the simulation time by a factor of 1000 when compared to the standard MC tools. Currently, FRED is already used as a research tool at several clinical and research centers for proton beams while for carbon and electron beams is under development. Using FRED we have simulated in detail the LIAC HWL mobile IORT accelerator produced by SIT, and we have developed an optimization tool that, starting from the CT imaging, explores different combinations of energy beam, applicator dimension, and position in a few seconds. We have then combined the FRED simulation with a simple modeling of the FLASH effect.
Results: The tumor coverage and the dose absorbed by the organs at risk have been compared, carrying out a quantitative analysis adopting Dose Volume Histograms (DVH).
Conclusions: The results demonstrate the potential of FRED as a tool for treatment planning and of the FLASH effect in IORT treatments.

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CLINICAL COMMISSIONING OF THE FIRST POINT-OF-CARE SPECTRAL PHOTON-COUNTING CT FOR THE UPPER EXTREMITIES

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Purpose: To assess the image quality and dose performance of the first dedicated spectral photon-counting CT (SPCCT) for extremity imaging, and establish a comprehensive quality assurance (QA) program for SPCCT systems.
Material and methods: The MARS Extremity 5X120 is a small-bore SPCCT scanner designed for conducting clinical investigations on the upper extremities. The scanner integrates a detection unit composed of twelve CdZnTe-Medipix3RX chips able to measure five energy bins simultaneously and to provide a 0.1 mm voxel size. Basic image quality metrics such as CT number accuracy and uniformity of water and noise level were evaluated by scanning adapted CT phantoms. The in-plane spatial resolution was calculated through the modulation transfer function (MTF). Slice thickness and the longitudinal spatial resolution (Z-direction) were assessed using a thin high contrast wire in air. Image noise was evaluated in the frequency space by calculating the noise power spectra (NPS). We used various high- and low-Z materials to study the material discrimination capabilities. The volume dose index (CTDIvol) was measured on a custom-made 10 cm CTDI-like phantom. We carried out a complete radiation survey to measure the radiation exposure at different points around the scanner. Basic metrics were evaluated to determine whether they met QA standards. Revised tolerance levels were proposed to fit the specifications of the MARS scanner.
Results: CT number of water, uniformity, noise level and slice thickness met the technical requirements. The signal-to-noise ratio was measured and proposed as a quality indicator for SPCCT systems with voxels calibrated in linear attenuation coefficients. The in-plane and longitudinal spatial resolution were about 1.5 lp/mm and 5.0 lp/mm (10% MTF), respectively. NPS results showed less noise correlation in the longitudinal direction than in the axial plane consistent with a better spatial resolution in the Z-direction. We measured a good spectral correlation and linearity for all high-Z materials. The CTDIvol for the routine hand and wrist protocol (118 kVp, 30 uA) was 9.81 mGy, equivalent to 3.82 mGy for a standard 32 cm CTDI phantom. The radiation survey showed that the scanner is fully shielded except at the gantry access port.
Conclusions: New phantoms, suitable metrics, and automated analyses were proposed to assess the technical performance of the MARS Extremity 5X120 CT in terms of image quality and radiation dose. Results indicate that the MARS scanner satisfies all technical

specifications and complies with international standards. This study establish a comprehensive QA program for SPCCT systems.

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DETECTION OF INTER-FRACTION MORPHOLOGICAL VARIATIONS IN 12C IONS TREATMENTS: RESULTS FROM A CLINICAL TRIAL AT CNAO FACILITY

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Purpose: The application of safety margins in treatment planning to account for possible morphological variations limits particle therapy intrinsic potential requiring the implementation of safety factors. The development of an in vivo verification system, still missing in clinical routine, is hence considered a crucial step forward in improving the clinical outcome, allowing to experimentally check the planned and delivered dose consistency and to re-schedule the treatment whenever needed. The Dose Profiler (DP) is a device designed and built to operate as an online verification system of 12C ion treatments, exploiting the secondary charged fragments escaping from the patient body. The DP capability of spotting morphological variations occurring during the treatment delivery (that can last up to four weeks) has been investigated for pathologies of the neck-head district in the context of a clinical trial (ClinicalTrials.gov Identifier: NCT03662373) carried out at CNAO (Centro Nazionale di Adroterapia Oncologica, Pavia, Italy) from the INSIDE collaboration.
Material and methods: After each monitored fraction, the 3D image of the fragments' emission positions is compared against the one obtained in the first fraction. Differences in the fragment emission maps correlated to morphological variations have been already observed comparing the 1D projections along the beam direction. A 3D comparison strategy based on the gamma-index calculation has been implemented to allow for better and easier localisation of the spotted variations ad improve the technique sensitivity.
Results: The 3D gamma-index maps have been calculated for 10 patients enrolled in the clinical trial and the results were used to study the correlation between the morphological variations that occurred (in three patients) and the dose map changes. The obtained results are demonstrating the technique's potential in spotting inter-fraction morphological changes and that it could be a valuable help to alert the medical team allowing to evaluate the need for an early re-evaluation CT and a treatment re-planning.
Conclusions: The results of the analysis performed on patients enrolled in the trial clearly indicate that early detection of morphological changes occurring in the tissues crossed by the beam in its entrance path towards the target volume is possible using the DP as a monitoring device. In the next months, other ten patients will be recruited to study and validate the technique on different pathologies, finalising the systematic uncertainty studies and technique sensitivity evaluation.

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DOSIMETRY OF SALIVARY GLANDS IN 18F-PSMA-1007 PET/CT: A COMPARATIVE STUDY OF DIFFERENT METHODS

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Purpose: Prostate-Specific Membrane Antigen (PSMA) radiolabelled ligands are used for diagnosis and therapy of prostate cancer (PS) recurrences. Salivary glands (SGs) are the dose-limiting organ in PSMA-targeted radionuclide therapies [1,2]. Aim of this work was to compare three different dosimetry methods for SGs absorbed doses (ADs) calculation following the administration of 18F-PSMA-1007.
Material and methods: Five patients with biochemical PS recurrence were prospectively enrolled at the "Mater Domini" University Hospital of Catanzaro (IT). Each patient underwent three quantitative PET/CT acquisitions, 20 min, 2 hours and 4 hours after 18F-PSMA-1007 injection, respectively. Morphologic Volumes Of Interest (VOIs) of the parotid and submandibular glands were manually segmented on the first time-point CTs. ADs to SGs were calculated with the following methods:
M1) Spherical model (SM) of OLINDA/EXM 2.1, defining spherical SGs with same volume and mass of the morphologic VOIs. Input Time-Integrated Activity Coefficients (TIACs) were obtained from trapezoid integration followed by physical-decay tail according to sequential PET/CT data.
M2) Ellipsoidal model (EM) by Amato et al. [3], using 3D Slicer to define SGs axes and employing the same TIACs of M1 in home-implemented spreadsheets.
M3) Patient-specific dosimetry via GATE Monte Carlo (MC) simulations, with sequential PET/CTs used as input to evaluate 3D dose rate (DR) maps and calculate the average DRs in SGs VOIs to be integrated with trapezoid + physical-decay tail. To account for activity spill-out with respect to morphological SGs VOIs, a signal-threshold method (25% of the maximum PET activity) was used to define the total activities in SGs.
Results: SM and EM produced almost identical results for all the four SGs VOIs and all the patients, with relative differences within 1% also in the cases of ellipsoids of higher eccentricity among the ones defined. Both SM and EM showed to underestimate absorbed dose in SGs by about 10-15% with respect to MC, for all the VOIs and patients examined.
Conclusions: The present study shows that SM and EM produce a systematic underestimation of patient-specific 18F-PSMA-1007 SGs ADs compared to MC. This can be explained i) by the fact that SM and EM do not account for cross-dose due to emissions in the surrounding uptaking tissues of the head-neck district - including

the other SGs -, and ii) by the simplified implementation of the SGs geometry as spheres or ellipsoids.

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THE DEVELOPMENT OF AN EARLY CAREERS - SPECIAL INTEREST GROUP (EC-SIG); THE EXPERIENCE OF THE IRISH ASSOCIATION OF PHYSICISTS IN MEDICINE (IAPM)

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Introduction: A recent publication in Physica Medica, (Marcu et al., 2022 [1]) discussed a survey conducted by EFOMP on the formation of an Early Careers (EC) group within the federation.

Results of this survey show wide support for such a group, and revealed that many National Member Organisations (NMOs), not currently having a dedicated EC group, are giving consideration to their establishment at national level also.

As one NMO within EFOMP having recently set up an Early Careers – Special Interest Group (EC-SIG), the Irish Association of Physicists in Medicine (IAPM) shares its experience, that it may encourage and assist those NMOs considering the formation of their own group.

Methods: 23rd May 2019, with support of the IAPM Council, the EC-SIG was established through an inaugural meeting of a number of early career physicists. The purpose and goal of the EC-SIG was to provide a forum through which trainee and junior physicists could network amongst themselves, share their knowledge and experience, identify common gaps in, and take an active role in supplementing and standardising, aspects of their education and training.

Results: To date, the EC-SIG has held a number of networking, social, and other events, including workshops in developing coding skills (Python and MATLAB), Nuclear Medicine Dosimetry, and Dental Radiology. These workshops, open to all members of the IAPM, were well attended by both early career physicists, as well as by senior colleagues, choosing either to refresh their existing knowledge or develop new skills. The attendance by senior colleagues is welcome as it allows for additional knowledge and experience transfer in an informal capacity.

The EC-SIG now serves as a conduit through which early career physicists are made aware of professional matters affecting them, these topics are debated and discussed, and feedback is directed to the IAPM and senior colleagues.

Through all the above, it is used to strengthen relationships across the profession, as well as promote and standardise approaches to important topics such as education and training.

Conclusion: While still in its infancy, the establishment of the IAPM EC-SIG has been a successful endeavour. This is primarily due to the active participation and engagement of its members, as well as the consistent support offered by the IAPM and senior colleagues. The EC-SIG boasts many of the benefits discussed in the EFOMP survey and the group would strongly encourage early career physicists within Europe to develop their own national groups.

Reference:

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EVALUATION OF OPERATOR EYE EXPOSURE AND EYE PROTECTIVE DEVICES IN INTERVENTIONAL RADIOLOGY: PRELIMINARY RESULTS ON CLINICAL STAFF AND PHANTOM

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Purpose: The 2013/59 Euratom Directive, which mandates the reduction of the annual eye lens dose limits down to 20 mSv/years, concerns the clinical staff performing relatively high dose interventional radiology procedures. This study aimed to measure the occupational eye lens dose based on clinical measurements with passive personal dosimeters worn by Radiologists during various types of procedures and to assess the effectiveness of different eye protective devices.

Methods: Five Radiologists were monitored during procedures performed from 01/09/2021 in the interventional radiology department. All subjects were equipped with lead apron, thyroid collar and eye protective device (wraparound glasses of 0.75/0.50 mmPb front/side shield or half-face mask of 0.12 mmPb shield), 2 film-badges (calibrated in Hp(10)) placed over and under the lead apron at the chest level, respectively), and 2 TLDs (calibrated in Hp(3)) placed over and under the left side of eye protection device, respectively The dosimeters were read out after every two months period. Total-body exposure was assessed by weighting the Hp(10) values measured above and under the apron. The numbers, types, and air Kerma-Area Product (KAP) of procedures performed during the monitoring period were also recorded by the dose management system. The correlations between eye lens dose (Hp(3) measurement under the eye protective device) with thorax dose (Hp(10) measurement above the lead apron), KAP and number of procedures were studied and the dose reduction factors (DRF) of the various eye protections were assessed.

Results: A total of 737 procedures were performed to date in the observation period, with a monthly average of 24±11 procedures per Radiologist. The average monthly KAP per Radiologist was 1425±566 $Gycm^2$ (719-2308 $Gycm^2$). The average monthly total-body and eye lens exposures were 129±60 μSv (22-207 μSv) and 0.54±0.34 mSv (0.11-1.02 mSv) respectively. Ratios between eye lens dose with thorax dose and KAP varies greatly from operators and eye protections. Average ratios between eye lens and thorax doses of 0.24±0.20 (r=0.83) and 0.53±0.11 (r=0.99) were obtained for mask and glasses respectively. Average ratios between eye lens dose and KAP of 0.32±0.20 $mSv/Gycm^2$ (r=0.90) and 0.45±0.32 $mSv/Gycm^2$ (r=0.88) were obtained for mask and glasses respectively. Average DRFs of 3.6±0.8 and 2.0±0.2 were obtained for mask and glasses respectively.

Conclusions: DRFs of different eye protective devices were determined in clinical conditions. Measurements in controlled conditions, with Rando phantom placed in the positions typical of the Radiologist performing the procedure, are ongoing to confirm the results on clinical staff.

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ESTIMATION OF EFFECTIVE AND ORGAN DOSES IN PATIENT UNDERGOING INTERVENTIONAL NEURORADIOLOGY PROCEDURES: PRELIMINARY RESULTS OF A MULTICENTER STUDY

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Purpose: Radiation doses to adult patients submitted to intracranial aneurysms treatments were assessed in multicenter study using DICOM Radiation Dose Structured Reports (RDSR) and Monte Carlo simulations. Conversion coefficients to estimate effective (E) and organ doses (HT) from the air Kerma-Area Product (KAP) values were determined.

Methods: Data of 33 procedures performed on three angiographic equipment (two monoplane and one biplane) installed in two centres were analysed: AlluraXper FD20, Azurion 7, AlluraXper FD20/10. Local settings and acquisition protocols were considered for both centres. The geometrical, technical and dosimetric data of 7150 irradiation events (5862 of fluoroscopy and 1288 of fluorography) and 44 CBCT were extracted from the RDSRs by automatic dose management system. These data included patient characteristics, geometrical factors (field size, projection angles, source-reference point distance, tube and table positions), kVp, beam filtration and KAP. The data about the irradiation events were included in the Montecarlo PCXMC software to calculate E and HT. Tube and table positions were used to reproduce the X-ray fields positions on the mathematical phantom. A preliminary characterization of the angiographic equipment was necessary to assess the direction and the accuracy of movements performed during the procedure. Finally, E/KAP and HT/KAP coefficients were estimated. Bland-Altman method was used to assess the agreement between E estimated with Montecarlo methods (EMC) and E estimated using conversion coefficient (ECC).

Results: Large variations in KAP (range: 69÷561 Gycm^2) and E (range: 4÷73 mSv) were observed among procedures. Fluoroscopy, fluorography and CBCT modes contributed on average to 37%, 62% and 1% of E respectively. The most exposed organs were brain (640±376 mSv); oral mucosa (211±113 mSv); salivary glands (298±158 mSv); skeleton (207±98 mSv); thyroid (31±34 mSv). E/KAP coefficients of 0.09±0.02 and 0.08±0.02 mSv/Gycm^2 were obtained for the two centres, respectively (p=0.31). A good agreement was obtained between EMC and ECC, with a systematic difference of –0.4 mSv (limits of agreement of -14÷13 mSv). No statistically significant difference between centres was observed on HT/KAP coefficients of the most exposed organs exception done for the thyroid (p=0.02).

Conclusions: The E/KAP coefficient of 0.09±0.02 mSv/Gycm^2 was established for interventional neuroradiology procedures in a multi-institutional context. HT/KAP coefficients of 2.19±0.59 mSv/Gycm^2 for brain, 0.81±0.40 mSv/Gycm^2 for oral mucosa, 1.12±0.50 mSv/Gycm^2 for salivary glands, 0.73±0.12 mSv/Gycm^2 for skeleton, 0.12±0.14 mSv/Gycm^2 for thyroid were determined. The study is in progress to increase the number of patients to improve the robustness of the results.

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THE USE OF AN ANTHROPOMORPHIC PROSTATE SIMULATOR IN A TRANSRECTAL ULTRASOUND IMAGING TRAINING WORKSHOP FOR MEDICAL PHYSICISTS

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There are a number of benefits associated with low dose rate (LDR) prostate brachytherapy (PBT) including improved patient outcomes and quality of-life profiles, and the lower cost associated with the procedure over other treatment options. These benefits rest on a high quality PBT service; including highly trained staff, high quality equipment and a cycle of peer-review and continued learning. The Royal College of Radiologists recommend a minimum number of implants per centre per year, to ensure adequate ongoing experience in the procedure. The current recommended framework for skill acquisition for the PBT procedure, is similar to other surgical techniques in that it requires a case load for trainees to observe and be mentored through a number of procedures before they become competent and autonomous members of the brachytherapy team. A noticeable decline in the number of PBT cases has been observed despite reports that PBT has similar or superior outcomes to other patient modalities, and is more cost-effective with low morbidity. The decrease in prescription will affect the number of trainees and the number of suitably qualified mentors available to mentor and supervise training. This study describes the design and preliminary evaluation of a simulation-based transrectal ultrasound (TRUS) imaging training workshop developed for medical physicists involved in LDR PBT.

This was a prospective study involving nine medical physicists, invited from medical physics departments delivering LDR trans-perineal permanent seed PBT. The study incorporated a high-fidelity anthropomorphic PBT TRUS training simulator and a TRUS imaging module with a blended learning pedagogical approach, to address TRUS image optimization and managing image quality during the PBT TRUS procedure. This was a mixed-methods study, collecting pre and post quantitative data from participants through MCQ questions and questionnaires, and qualitative data was collected through two focus groups.

The results demonstrated there was a significant improvement in knowledge, with an average increase in MCQ score of 61% (P<0.0002), there was a 46% (P<0.0001) average increase in the participants understanding of TRUS scanner operation, and an increase of 36% (P<0.001) in participants readiness to optimize image quality and mitigate image artefacts.

This study suggests that there is a benefit in offering a simulation training workshop to medical physicists involved in LDR prostate brachytherapy. The novel high-fidelity anthropomorphic PBT TRUS training simulators are efficacious because they provide a safe simulated environment to practice ultrasound image optimization for PBT image guidance, outside the surgical environment without direct exposure to patients.

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DIGITAL SKILLS GAPS OF MEDICAL PHYSICISTS ACROSS EUROPE

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Purpose: The digital transformation of modern healthcare makes digital skills even more essential for Medical Physicists (MPs). Digital solutions have the potential to radically transform health systems by providing better results and improving quality of services. The digital skills gaps in the health sector affect the efficiency of health services and have a significant impact on society. This study aims to identify professional knowledge gaps in digital skills and specific training needs of MPs across Europe as a part of a wider research project, the DIGI4ME under ERASMUS+, which aims to address skills gaps of the healthcare workforce and provide a training framework.
Material and methods: A Delphi study was conducted between February and October 2021 among MPs in Europe. Data collection comprised of questionnaires and interviews.
Results: Results show that the level of digital skills of MPs is low as far as the use of advanced database management tools and big data analysis is concerned, since more than 40% of the participants did not have knowledge. More than 25% of the participants need guidance to compress images and remove patient information from medical image data, which is crucial for the fulfilment GDPR. The areas that MPs express interest on advanced training, are new methods of text input, use of appropriate monitor for each modality, DICOM functions and software tools, 3D imaging reconstructions, virtual processing tools, advance computer aided diagnosis tools and use of basic database tools. On the other hand, MPs seem to be in advanced level and capable of training others in many professionally specific areas; 25-30% on devices to input and process data, on DICOM jargon and on image processing tools; 20-24% on diagnostic monitors and on the environmental conditions for each modality, on qualitative and quantitative analysis, on DICOM images structure, information extraction from header and conversion to other formats, on the effect of image characteristics to file size and differences on image characteristics among modalities. All results are statistically significant.
Conclusions: This study identified a considerable number of digital skills that need to be developed amongst MPs. The findings will help to design effective Vocational Training programs and help MPs to develop or update their skills. The provision of such trainings will have a positive impact on MPs' daily routine tasks, but also promote collaboration and networking between healthcare professionals such as radiographers, radiotherapy or nuclear medicine doctors, which is vital for a multidisciplinary approach.

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FLASHDC: DEVELOPMENT OF A BEAM MONITORING SYSTEM FOR FLASH RADIOTHERAPY

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Purpose: Conventional Radiotherapy is one of the leading techniques in tumor treatment, used in addition or in alternative to surgery and chemotherapy in approximately 60-70% of cancer patients. However, it suffers an intrinsic limitation due to additional dose released on healthy tissues associated with the risk of neoplasms and late complications, leaving a large portion of tumors close to organs at risk and/or radioresistant without adequate remedies. The landscape could significantly change in light of recent preclinical studies showing evidence of a new phenomenon, dubbed as FLASH effect, consisting of a strong toxicity reduction in healthy tissues (down to 60%) while maintaining high tumor control probability, when the mean dose rate is increased at more than 40 Gy/s. The beneficial impact of FLASH effect in clinical practice would be incalculable, but there are many open questions to be addressed before its implementation in treatment plans. One of the greatest challenges is related to the beam control and treatment verification, as there are no present technologies for beam monitoring fit for clinical dosimetric and quality assurance requirements in the FLASH regime, since most conventional monitors suffer non-recoverable saturation effects and/or beam energy dependences at ultra-high dose rates.
Material and methods: The Flash Detector beam Counter – FlashDC – project aims at developing an innovative and economical detection system, with high spatial and temporal resolution, minimal impact on the beam line and capable to efficiently work on the widest possible range of configurations for FLASH machines (wrt type of particle, energy, pulse duration etc.). The detector exploits the physical principle of air fluorescence to overcome the current limitations of standard monitoring technologies, since it provides a signal unsaturated by the high number of particles per pulse with a very wide dynamic range (typical 10^{12} electron/pulse).
Results: Several prototypes, with air as the active volume, readout by two photomultipliers, have been used for proof of principle studies and test beam campaigns, measuring the fluorescence signal with respect to beam position and intensity, and a Monte Carlo simulation with the FLUKA software has been developed to estimate the light output and detection efficiency under FLASH working conditions and finalize the detector layout.
Conclusions: Preliminary measurements using prototypes have given promising results. The final detector will be able to monitor the instantaneous intensity of typical FLASH pulses with spatial resolution ~ mm, maintaining a response linearity with respect to dose rate up to 10^2–10^3 Gy/s.

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PROTOTYPE OF A LINE-FOCUS X-RAY TUBE (LFXT) AS COMPACT SOURCE FOR MICROBEAM AND FLASH RADIOTHERAPY

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Background: Microbeam (MRT) and x-ray FLASH radiotherapy have shown superior healthy tissue tolerance at tumour control rates comparable to those of conventional radiotherapy. As these methods place high demands on radiation quality, most research and all possible clinical applications are currently limited to large third-generation synchrotrons, impeding a translation into clinical routine. Compact and less complex alternatives to synchrotrons are required to facilitate a translation of both techniques into clinical routine. The line focus x-ray tube (LFxT) is a high-power rotating-target x-ray tube that focuses an extremely asymmetric electron beam onto a rapidly rotating target – thus shifting operation into the heat-capacity limit and enabling the generation of so far unachievable dose rates at small focal spot sizes. The LFxT is a promising technique for hospital based MRT and x-ray FLASH therapy, but also advanced x-ray imaging techniques.
Methods: We developed a first preclinical prototype of the LFxT designed for an electron beam current of 0.3 A at 300 kV acceleration voltage. To achieve this, we developed a low emittance electron source featuring a highly asymmetric focal spot and a target-rotor system allowing for surface velocities above 130 m/s, while being able to withstand the mechanical stresses produced by the rotational force and high thermal gradients. The radiological and thermal properties of the x-ray source were assessed in numerical simulations. A system of temperature and radiation detectors can monitor and validate the performance of the source experimentally. A powerful cooling system dissipates the enormous amounts of excess heat. We tackle the specific high-voltage and radiation risks with a bespoken shielding, safety and control system.
Results: Simulations have shown a 50 µm wide and 20 mm long focal spot achieving a dose rate of 10 Gy/s at 20 cm from the focal spot. At maximum power, a duty-cycle of 20 s irradiation, during which the focal spot temperature exceeds 2000 °C, followed by 20 min cooling is reached. Using a NIR-camera and an x-ray detector, the focal spot will be measured with a resolution down to 5 µm.
Conclusion: The prototype aims to prove the LFxT concept and validate the heat-capacity limit. Additionally, preclinical studies for MRT will be conducted and its imaging capabilities will be explored. In a next step, we will upgrade to a clinical prototype for an electron beam power of 1.5 MW at an acceleration voltage of 600 kV, achieving dose rates of more than 100 Gy/s.

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ADJUSTABLE MINIBEAM COLLIMATOR FOR PHOTON IRRADIATION

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Minibeam irradiation is an innovative radiotherapy method utilizing spatial fractionation to reduce healthy tissue toxicity while rigorously controlling the tumor. Although the mechanism remains unknown, one theory for this "minibeam-effect" is that hydrogen peroxide is necessary. To understand this effect, an adjustable collimator with interchangeable peak widths (PW) and valley widths (VW) is needed. However, minibeam collimators are expensive, require demanding production processes and cannot be easily adapted to each user. Therefore, this study aims to design and construct an adjustable and low-cost minibeam collimator to create a huge variety in PW and VW in a single collimator. Additionally, its applicability for future studies was assessed by various dosimetric parameters.
For this, a minibeam holder skeleton was designed in Autodesk Inventor and 3D printed with a size of 100mm×100mm. In the middle, a hole (25mm×25mm) and two elevations were implemented to arrange successive steel plates (40mm×10mm and a width of 0.5, 1, 1.5 and 2mm) and 3D printed plastic plates creating peak and valley regions. Adaptable to the need of the user these plates can easily be exchanged and reproducibly stacked with two screws. For the dosimetric characterization of the different configurations, EBTXD films and H460 cells were irradiated with a Faxitron Multirad 225 at 200kV.
We created a collimator with easily exchangeable leaves to generate dose profiles with PW and VW between 0.5 and 2mm. For all setups, the FWHM remains constant over the irradiated area and deviates maximally 10% compared to the collimator size. Peak and valley doses behave linearly to the applied doses and the peak to valley dose ratio (PVDR) for the different collimator setups remains constant between 2.1 and 2.7. In a preliminary in vitro experiment, irradiating H460 cells with 20Gy using the 1mm/1mm collimator results in a moderate growth delay which is not observed in cells irradiated with a 2mm/2mm collimator. This difference in cell growth cannot be explained by dose alone and thus suggest a role for hydrogen peroxide in the valley region of the 1mm/1mm collimator. To summarize, our novel adjustable collimator achieved dose profiles that are in accordance with the geometry as well as homogeneity in peak and valley doses over the irradiated area. The next step will be exchanging steel with tungsten plates to increase PVDR for in vitro and in vivo irradiation, to further explore the cellular mechanism behind the efficacy of minibeams.

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INVESTIGATING THE EFFECT OF EXPOSURE CONDITIONS ON IMAGE QUALITY OF DIGITAL MAMMOGRAPHY USING A SIMPLE MAMOGRAPHY PHANTOM AND DEDICATED FREE SOFTWARE

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Purpose: The International Atomic Energy Agency (IAEA) has launched a coordinated research project (CRP) on "Advanced Tools for Quality and Dosimetry of Digital Imaging in Radiology" (henceforth referred to as E242025 CRP). The goal of this project is to implement a method of automated evaluation of image quality in radiography and mammography, which is based on an inexpensive and easy to construct phantoms (made from PMMA, Copper and Aluminum) and free software (Tool for Image Analysis-ATIA) for the automated calculation of various image quality metrics from the phantom's images. In this study, the effect of exposure parameters on the image quality of digital mammography was investigated using this method and the first prototype of the mammography phantom.

Material and methods: The mammographic phantom was constructed according to the instructions described in the relevant documentation of the E242025 CRP (IAEA Human Health Series No.39). The phantom was imaged with a single digital mammography unit (Hologic Selenia Dimensions), using various combinations of tube voltage (kVp), AEC density (dose) settings, filter (Rh, Ag), mainly with grid but also without grid. The entrance skin dose (ESD), average glandular dose (AGD), and exposure index (EI) values displayed after the end of each exposure were recorded. The image quality of the images acquired with different exposure conditions were analyzed using the ATIA software.
Results: For each digital image of the phantom, the ATIA software calculates the modulation transfer function (MTF) at various modulation levels (MTF50%, MTF20% and MTF10%) in both directions (horizontal and vertical), the signal difference to noise ratio (SDNR), the signal to noise ratio (SNR) and the detectability index (d') for details of two sizes (diameter 0.1 and 0.25 mm). With increased AEC density settings, the horizontal MTF was relatively stable (though the vertical MTF50% exhibited a slight decrease), while SDNR, SNR and d' increased. The MTF metrics showed a mixed behavior with kV increase and when changing the filter from Rh to Ag, but SDNR, SNR and d' decreased. Without grid the MTF and SNR were reduced by up to about 20% but SDNR and d' were almost halved.
Conclusion: This method is very sensitive regarding the detection of changes in image quality due to change of exposure conditions. The image quality decreases with increasing kVp, decreasing AEC density setting, change of filter from Rh to Ag and when the grid is removed.

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DEVELOPMENT OF A CALCULATION TOOL TO APPLY RADIOBIOLOGICAL DOSE CORRECTIONS TO DOSE-VOLUME HISTOGRAMS TO ANALYSE PROSTATE TREATMENT PLANS

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Purpose: The purposes of this study were (i) to develop a calculation tool to apply radiobiological dose-correction to dose-volume histograms (DVH) and (ii) to analyse prostate treatment plans for patients who received combined external beam (EBRT) and brachytherapy (BT) treatments. The calculation tool should be compatible with different external beam and brachytherapy treatment planning systems.
Material and methods: The dicompyler-core Python package was used by the program to access standard DICOM dose and structure data. Radiobiological effects were incorporated by using the Linear-Quadratic model during dose-volume histogram calculation. The isoeffective dose formulation used was the EQD2 or Equivalent dose in 2-Gy fractions. Visual inspection and a gamma analysis method, were used to verify agreement of the DVH calculated by the correction tool, both qualitatively and quantitatively with those calculated by the different treatment planning systems: Monaco®HD and Vitesse™. For clinical analysis, five patient cases with malignant neoplasm of the prostate treated at the University Hospital Galway were studied. Documentation of physical and biological DVH point-dose metrics for combined EBRT and BT treatments was available per patient in the format known as GEC-ESTRO "Vienna Sheets". The DVH point dose metrics for organs at risk (OAR) were compared with the data from the program.
Results: The radiobiological correction program entitled BRED was successfully developed and verified. Visual comparison of the same DVH produced in both BRED and other TPS showed good agreement. Gamma analysis (ΔV% = 5%, ΔD% = 5%) showed passing rates of 97.55% and 94.29% for Monaco®HD and Vitesse™ respectively. The presence of sources in the target and prostate resulted in a higher Dmax due to BRED assuming the sources as part of the volume of interest. Analyses of the prostate cohort's individual dose-volume metrics (Urethra D0.1cc, D10, D30, and Rectum D2cc) showed an agreement within 5% of the BRED dose-volume metrics. The EQD2 DVH tool created DVHs across the full dose-range rather than point dose metrics thereby presenting extra information to enable clinical decision making.
Conclusions: The correction tool and the EQD2 DVH plots have the potential to be used clinically either as a way of assessing combined treatment plans or as a supplement to the Vienna Sheets. Care must be taken in adding EQD2 DVH plots with cases that have plans with varied prescription sites.

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A NOVEL PLANNING TOOL FOR RADIOBIOLOGICAL OPTIMIZATION OF THERMORADIOTHERAPY TREATMENTS

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Purpose: Thermoradiotherapy combines radiotherapy with tumour heating of 39-45°C to increase the therapeutic effect through thermal radiosensitization/cytotoxicity. Radiotherapy and hyperthermia plans are optimized individually and in state-of-the-art research the total thermoradiotherapy effect is evaluated using an equivalent radiation dose in 2-Gy fractions (EQD2). In this study, a novel planning tool is presented which accounts for the EQD2 directly in the radiotherapy optimization given LQ-parameters α and β, a thermoradiotherapy schedule and a temperature distribution.
Methods: The optimization tool was implemented in a research version of the radiotherapy planning system RayStation 11B. Thermal radiosensitization was modelled voxelwise, assuming an exponential temperature-dependent increase of the LQ-parameters, with an exponentially decreasing exponent with the time interval between corresponding radiotherapy and hyperthermia fractions, t_1. For a thermoradiotherapy treatment of n_1 radiotherapy fraction doses of d_i and n_2 hyperthermia fractions of temperature T_i during time t_2 to an arbitrary voxel i, the $EQD2_i$ was modelled as:
$EQD2_i = [\alpha_{ht,i}(T_i,t_1,n_2)\cdot d_i\cdot n_1 + \beta_{ht,i}(T_i,t_1,n_2)\cdot d_i^2\cdot n_1 + c_i(T_i,t_2,n_2)] \div [\alpha_i + 2\cdot\beta_i]$,
where α_i and β_i are the LQ-parameters without hyperthermia, $\alpha_{ht,i}(T_i,t_1,n_2)$ and $\beta_{ht,i}(T_i,t_1,n_2)$ are the effective LQ-parameters with hyperthermia, and $c_i(T_i,t_2,n_2)$ is the tumour-specific thermal cytotoxicity, all for voxel i. To demonstrate proof-of-concept, radiobiological optimization was performed for a prostate cancer patient. Heating with the ALBA-4D system was optimized using Plan2Heat. Subsequently, CT and temperature distribution were imported to RayStation and 3 VMAT plans were optimized:

- RT^{only}: homogeneous target EQD2 (α/β=1.5 Gy, n_1=20) of 78 Gy assuming no hyperthermia (n_2=0)
- $RTHT^{OAR}$: as (1), but with hyperthermia (n_2=8 and t_1=t_2=1 h, α/β=3 Gy) for organs-at-risk (OARs)
- $RTHT^{tumour}$: as (2) but aiming at a homogeneous EQD2 of 93 Gy accounting for hyperthermic effects to the tumour.

All plans were evaluated using EQD2 including hyperthermia (n_2=8, t_1=t_2=1 h), specifically scoring target homogeneity index (HI=$EQD2_{95}$÷$EQD2_5$), conformity index (CI=V_{95}^{target}÷V_{95}) and gradient index (GI=[V_{20}-V_{80}]÷V^{target}).
Results: Median target EQD2 was around 93 Gy for all plans, whereas the HI/CI of $RTHT^{tumour}$ (0.94/0.90) were superior compared to $RTHT^{OAR}$ (0.78/0.82) and RT^{only} (0.78/0.79) due to the inclusion of hyperthermic effects to the tumour in the optimization. $RTHT^{tumour}$ also had the lowest overall OAR burden with a GI of 10.32 compared to 11.98 and 12.24 for $RTHT^{OAR}$ and RT^{only}, respectively.
Conclusions: This novel planning tool exploits hyperthermic radiosensitization and cytotoxic effects in optimization, thereby improving the overall EQD2 distribution potentially leading to improved treatment outcome. This could be utilized in individualized pre-treatment planning as well as in adaptive schedules.

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MAPPING PROTON STOPPING POWER WITH DUAL ENERGY GENERATED VIRTUAL MONOENERGETIC IMAGES

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Purpose: To evaluate the accuracy and robustness of a novel method for predicting proton stopping power ratios (SPR) based on Dual Energy CT (DECT) generated virtual monoenergetic images (VMI). In the evaluation we compare results to another DECT method, based on native kilovoltage (kV) images.
Material and methods: The VMI-based method works by applying a well-established physical model for photon interaction by Jackson and Hawkes directly on pairs of VMI, with no further approximations. The resulting system of equations can be solved for two physical parameters, the effective atomic number and electron density, which are then used to estimate proton SPR.
Image data of a CIRS-062M phantom from two different CT scanners (GE Healthcare and Siemens Healthineers) was used to reconstruct VMI and kV images. The VMI-based method was applied to every possible pairing of VMI in the range 40 to 140 keV, and cross-checked against a set of theoretical reference tissues, to find the optimal VMI pairs for SPR prediction in lung tissue, soft tissue, and bone. The kV image-based method was calibrated against the phantom manufacturer specifications. The impact of different scan and reconstruction parameters was investigated for the VMI-based method.
Results: While experimentally acquired SPR depend on the VMI pair used as input, the dependency in the theoretical results was small, implying that this dependency is a construct of the imaging chain and the CT scanner's ability to accurately reproduce true monoenergetic images, not intrinsic to the method itself.
For the Siemens Healthineers scanner (dual source DECT), the SPR root mean square errors (RMSE) yielded by the VMI-based method (1.6% for lung tissue, 0.4% for soft tissue, and 0.8% for bone) improved on the kV image-based method (2.5% for lung tissue, 0.7% for soft tissue, 3.7% for bone). On the GE Healthcare scanner (fast kV-switching DECT), the VMI-based method yielded the following RMSE: 4.1% for lung tissue, 0.4% for soft tissue, and 0.7% for bone.
No dependency was found between the VMI-based method's SPR prediction and level of noise reduction, there was no identifiable trend in results for different image reconstruction kernels, and variations with dose level were within or around two standard deviations.
Conclusions: The proposed VMI-based method demonstrates accuracy comparable to kV image-based methods for SPR mapping, is robust to changes in imaging and scan parameters, and in contrast to kV image-based methods, directly applicable on all DECT systems capable of reconstructing VMI.

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A STRANGE KIND OF RING SHAPED ARTIFACT ON A LOW DOSE PEDIATRIC CHEST CT EXAM: CASE STUDY AND REPLICATION OF THE ARTIFACT WITH A PHANTOM

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Abstract: To investigate the shape and possible causes of an unusual ring-shaped artifact presenting in a low dose pediatric chest CT and to replicate the visible effect by means of a phantom, in order to understand why it occurred and how it can be avoided to preserve image quality and diagnostic outcome.
Methods: Scientific articles and guidelines were reviewed to find similar artifacts with no success. Discussions with professionals involved in the exam execution were conducted to find causes and problems. A plastic cylinder was used as a phantom miming a pediatric patient to simulate the artifact, in order to replicate the same conditions and acquisition parameters of the exam to disentangle and study single hypothetical causes.
Results: Similar circle-shaped artifacts were observed on the replicated CT with the phantom. Possible causes of the artifact were: shift of the patient position with respect to the central axis; reconstruction of phantom's images centered taking into account metallic object in the field of view (FOV); change of the patient position between survey pre-scan and final CT acquisition;
Conclusion: In order to avoid the artifacts the following actions should be performed: correct centering of the patient; reconstruction FOV must be centered on the anatomic part of interest; topogram should include only the anatomical region of interest; remove all metallic objects present. In clinical cases in which it is impossible to remove metallic objects, it is necessary to include them both in the acquisition and reconstruction FOV. If a metallic object is present only in the scout image but absent in the final CT image, it contributes to generating the artifact.

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DETERMINING TYPICAL PATIENT EFFECTIVE DOSE LEVELS USING A DOSE MONITORING SYSTEM FOR OPTIMIZATION STUDIES: APPLICATION TO DENTAL CONE BEAM CT IMAGING

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Purpose: To use a dose monitoring system for determining typical patient effective dose levels for optimization studies of x-ray exposures, with a focus on dental cone beam CT (CBCT) imaging.
Material and methods: A dose monitoring system (DOSE, Qaelum NV, Belgium) was used to collect radiation exposure data (i.e. the recorded Dose Area Product (DAP) value in dGy.cm^2, Field Of View (FOV) selection in cm^2, and the system operation mode), as well as

the patient age for 5163 dental CBCT examinations performed in the university hospital of Leuven from January to December 2019, just prior to the Covid-19 pandemic. Examinations were performed on a 3D Accuitomo 170 (Morita, Japan) and a VGi EVO (NewTom, Italy) CBCT system. The extracted DAP values were corrected with an experimentally determined correction factor obtained during annual quality control tests. For each CBCT system, effective dose conversion factors (CFs) as a function of DAP and patient age were calculated and implemented in DOSE. CFs were determined for the following age groups: 4-6y, 7-11y, 12-14y, and >=15y. For the effective dose calculations, patient data was, for each system, further classified based on the selected FOV and operation mode. The FOV size was categorized into small (≤40 cm^2), medium (>40 cm^2 and ≤100 cm^2), or large (>100 cm^2).
Results: For the standard operation mode, average effective doses on the 3D Accuitomo 170 system as a function of age group were, from young to old: 77.7-300, 54.4-210, 39.9-154, 35.1-136 µSv, and for the VGi EVO system: 60.5-117, 12.1-97, 9.54-69.9, 9.26-61.5 µSv. For both systems, a decreasing trend in the effective dose with increasing age was observed. For each age group, the doses increased with increasing FOV size. The selected operation mode also influenced the dose to the patient (e.g. for the high-resolution mode on the VGi EVO system, 1.5-4 times higher effective doses were observed compared to the standard mode). The effective dose levels on the NewTom VGi evo system were significantly lower than on the 3D Accuitomo 170. For the VGi EVO system, the most frequently used system in clinical practice, the total radiation burden from the examinations was 0.22 manSv.
Conclusions: This was one of the first studies providing a complete 1 year overview of dental CBCT effective doses in a university hospital dental department. The results could be used for optimization studies and/or to situate the exposures in comparison to multislice CT or panoramic examinations.

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EVALUATION OF EYE LENS DOSE IN INTERVENTIONAL CARDIOLOGY USING 3D PRINTED PERSONALISED HEAD PHANTOMS

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Purpose: Interventional cardiologists are susceptible to high occupational radiation exposure due to the nature of the work they carry out. The eye dose limit for occupational category A workers was subject to a seven-fold reduction from 150 mSv to 20 mSv per annum (EU Directive 13/59). This reduction resulted in revised radiation protection requirements for this staff group, including the wearing of lead protective glasses. Currently, regulators permit a dose reduction factor (DRF) of 2 if lead protective glasses are used. This study aims to measure actual DRF values for a range of lead glasses to determine if an optimal dose reduction factor can be achieved using 'best-fit' glasses for individuals following individualised fitting by a dispensing optician.
Methods and materials: A 3D printed head phantom was used to measure DRFs for a range of protective lead glasses. These glasses were professionally fit to the head phantom by a dispensing optician and rated from worst to best-fit in terms of both comfort and degree of radiation protection provided. To determine DRFs, a cardiologist was replicated in the Cath Lab using a Rando phantom with the head phantom on top. A range of dosimeters (nanoDot OSLs, Landauer and Ed3 extremity active dosimeters, JCS Nuclear Solutions) were placed on the head and the different glasses were evaluated. Fluoroscopic screening was carried out using a Siemens Artis Zee C-arm and the DRFs were determined at the lens of the eye by comparing the dose received with and without eye protection in place. Facial analysis software (Cliniface, SIS Research LTD) was used to analyse facial morphology of the phantom to characterise facial parameters with the fit of each pair of glasses.
Results: Dose reduction factors in the range of 4 to 6 were measured for different glasses using the Ed3 dosimeter. The nanoDot OSLs gave unreliable measurements and the data was not used. The facial analysis software tested was unable to determine facial features correctly on the head phantom. The glasses determined to have the 'best-fit' by the dispensing optician for the head phantom gave the highest dose reduction factor of 6.
Conclusion: This study shows that greater dose reduction factors than that recommended by the regulator are possible by wearing lead protective glasses that are professionally fitted. The DRF value of 2 currently used by regulators for lead glasses is conservative and further review is required.

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EXPERIENCE IN THE DISPOSAL OF LEAD PROTECTION FOR PATIENTS IN RADIOLOGY: PRACTICAL ASPECTS AND COMMUNICATION TO THE POPULATION AND HEALTHCARE PROFESSIONALS

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Abstract: Patient shielding is a common practice in diagnostic imaging while growing scientific evidence suggests that their use brings negligible or no benefit, potentially increase the dose to patients and loss of diagnostic information of images. Education of staff, patients and caregivers before abandoning their use is essential for practical and psychological reasons. An effective communication plan is mandatory for stakeholders, population and healthcare professionals.
Methods: Scientific articles, statements and positions of national and international associations were reviewed. Discussion with professionals and meetings with public and private institutions were conducted. Information and education for practitioners and operators about scientific and practical aspects were realized. Professional societies and other pertinent organizations were involved in the development of a communication plan and procedure instructions. Communication to population and patients was realized through webinar, poster, oral communications, articles published on several newspaper and websites, also in flyers coded in "easy language" (level B1) reviewed by specialized associations.
Results: Good feedback was obtained during dedicated training and information with associations of citizens and professionals, parent-child assemblies, Swiss-Italian patient associations, local healthcare department, elderly association, medical radiographers associations, medical practice assistants, healthcare professional schools and orders of Physicians, medical doctors and dentists.

Conclusion: Shielding discontinuation was concluded with success and without significant impact on patients, work practice and staff members. A rigorously planned communication strategy should be organized to help the population, professionals and patients to understand the reasons and effects of discontinuing lead shielding without impacting activities and diagnostic exams.

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CLINICAL EVALUATION OF DEEP-LEARNING BASED IMAGE RECONSTRUCTION IN PEDIATRIC HEAD CT SCANS

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Purpose: Advancements in CT technology have brought new image reconstruction techniques available such as deep-learning (DL) based image reconstruction (DLR). The aim of this study was to evaluate pediatric head CT image quality produced by DLR in comparison with iterative reconstruction (IR) by subjective radiologist review and objective image analysis.

Material and methods: Head CT scans were performed with GE Revolution 256-slice scanner (GE Healthcare, Milwaukee, WI, USA) in normal clinical workflow to 28 patients (14 males and 14 females) ranging from 8 months to 19 years of age (mean age 8 years). Scan parameters were 120 kV, 0.35 s rotation time, axial scan mode, angular tube current modulation with noise index of 6.3 HU, CTDIvol 27±7 mGy (mean±SD). Three experienced neuroradiologists evaluated subjective image quality based on four criteria: contrast, noise, spatial resolution, and artefacts. Likert scale (1 to 5) was used in the evaluation where score value 3 indicated equal level, values 1 to 2 indicated inferiority and values 4 to 5 indicated superiority of the DLR image quality with the IR method, respectively. Objective image quality was assessed for contrast and noise using spherical 3D region-of-interest (ROI) analysis from the thalamus (gray matter) and centrum semiovale (white matter) regions. Subtraction images (IR - DLR) were also qualitatively reviewed and used to verify ROI location homogeneity. DL based image noise assessment was also applied as an alternative method for image quality measurement.

Results: Subjective results in all evaluation criteria showed systematically improved image quality of DLR over IR. The mean (and SD) subjective Likert scores for different image features for DLRmedium and DLRhigh, respectively, were the following: contrast 3.7 (0.3) and 4.3 (0.4), noise 3.7 (0.3) and 4.4 (0.5), resolution 3.7 (0.3) and 4.1 (0.3), and artefacts 3.5 (0.3) and 3.7 (0.2), respectively. The greatest subjective improvement from DLRmedium to DLRhigh was observed for the noise (+0.7) and the smallest improvement was observed for the artefacts (+0.2). Objective measurements showed no contrast change seen in the mean CT numbers. The mean image noise decreased (min–max range) 25% (22%–27%) and 43% (40%–45%) with DLRmedium and DLRhigh, respectively. Subtraction images presented contrast patterns mainly in bony edges and reduced beam hardening effects.

Conclusion: DLR in head CT scans provided improved clinical image quality as compared to routine IR method. Decrease of image noise in DLR images implies notable dose reduction potential in pediatric CT scans.

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IMAGE QUALITY DRIVEN OPTIMISATION IN DIAGNOSTIC RADIOLOGY; A FEASIBILITY STUDY FOCUSSING ON SHOULDER IMAGING PROTOCOLS ACROSS GENERAL X-RAY ROOMS IN THREE HOSPITALS IN THE REPUBLIC OF IRELAND

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Purpose: Optimisation efforts in diagnostic imaging are typically initiated using dose audit data. Although effective in identifying x-ray protocols that generate statistically high or low doses, the approach doesn't consider image quality. The overarching objective of this work was to investigate the feasibility of an image quality driven approach to optimisation.

A high level of variability in pre-set exposure factors for shoulder examinations was identified at an early stage, flagging shoulder imaging as a prime candidate for the trial 'image quality driven' optimisation exercise. Secondary objectives for this work were to assess the degree of non-standardisation evident in pre-set shoulder imaging protocols in terms of exposure factors, and associated dose and image quality.

Material and methods: The pre-set exposure parameters from the ten DR rooms were retrieved from the operating consoles. Tube output measurements for each of the identified protocols were made. PCXMC was used to estimate the effective doses associated with each protocol. A test object containing varying-sized contrast details was imaged in each room with each protocol. The experimental set-up included scatter material, with a view to replicating a clinically realistic scenario. Images were analysed to extract a number of quantifiable metrics, namely contrast to noise ratio (CNR), resolution and varying detail detectability.

Results: Fourteen pre-set shoulder imaging protocols across the ten DR rooms were identified. These had tube potentials ranging from 55-81 kV and tube currents from 2.5-8 mAs. The associated effective doses ranged from 1-41 uSv. The variation in CNR for each protocol was analysed in detail. The highest performing protocol demonstrated CNRs greater than 2 standard deviations from the mean in a number of rooms. It was specifically designed for Y view shoulder exposures, with a larger fixed mAs than typically engaged for a standard AP view. The associated dose was the second highest in the data set. Some of the lower dose protocols demonstrated strong CNR profiles too, marking them out as good all-round performers. Similar analyses were performed, comparing signal to noise ratio, resolution and detail detectability of the protocols.

Conclusions: The simple process implemented demonstrates scope to proceed with image quality driven optimisation in general x-ray rooms. CNR is a readily accessible metric with particular applicability when considering bony structure imaging. The initial findings specific to shoulder imaging indicate a high degree of non-standardisation in terms of exposure factors, inferred image quality and dose.

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GAUSSIAN PROCESS CLUSTERING TO STUDY PSA DYNAMICS IN PROSTATE CANCER PATIENTS

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Purpose: One in three men with prostate cancer experience biochemical recurrence (BCR), detected via rises in Prostate Specific

Antigen (PSA). We study post-treatment PSA dynamics using Gaussian process clustering over irregular and uneven time-series. We further investigate whether PSA dynamic information improves prognostic model performance.

Material and methods: Patient information, including repeat post-radiotherapy PSA measurements, was collected for 320 men treated with conformal hypo-fractionated radiotherapy at a single institution between 2004-2007.

PSA trajectories were modelled using Gaussian Process regression with a radial-basis-function kernel (pythonv3.6.5, sklearn). To study post-treatment dynamics, the log-difference in PSA from the first post-treatment measurement was calculated. To avoid bias due to further treatment interventions, PSA trajectories were modelled up to BCR (nadir+2ng/ml).

To deal with irregular and uneven time data, Gaussian processes were sampled at regular intervals (0.1years). The Euclidian distance between trajectories was calculated using the longest common subsequence, and trajectories assigned to one of two clusters using hierarchical clustering.

Association between BCR and cluster assignment was investigated via Kaplan-Meier and multivariable analysis (age, T-stage, Gleason, Androgen Depravation Therapy (ADT) duration, and baseline PSA) (Rstudiov4.0.5). Cox proportional-hazard models with and without PSA trajectory information were produced and the Akaike Information Criterion (AIC) used to assess model performance.

Results: 115/320 men recurred during follow-up, with 26 within 3-years of radiotherapy. Median time-to-recurrence and follow-up time was 5.6 and 6.8 years (range: 14 weeks–11.7 years) respectively. Patients had a mean of 16 PSA levels (range: 2–134), taken approximately 6 monthly (range: 3.5 weeks-2.2 years).

Kaplan-Meier analysis showed a significant difference in BCR between the two clusters, considering both BCR within 3-years of radiotherapy and BCR at any time as end-points ($p<0.0001$).

Cluster assignment was significantly associated with BCR in univariable and multivariable analysis (HR=3.45 (2.15,5.55), $p<0.001$). Baseline PSA was significant in univariable analysis (HR: 1.01 (1.01,1.01), $p<0.001$), but not in any multivariable analysis, suggesting that post-treatment PSA trajectory information was more informative.

AIC was significantly lower when cluster assignment was included in multivariable analysis ($p<0.001$).

Conclusions: We apply Gaussian process clustering to irregular and unequal time series data to cluster post-treatment PSA trajectories for men with prostate cancer. Results indicate that PSA trajectory information significantly improves model performance, and provide mechanism for better targeted follow-up. Results also indicate that PSA dynamics within the first 3-years of radiotherapy are prognostic of BCR at any time. Results will be validated in further data sets.

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BEAM ANGLE OPTIMIZATION FOR COMBINED IMRT AND FLASH RADIOTHERAPY

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Purpose: This study proposes a novel strategy for multi-beam FLASH radiotherapy that combines FLASH delivered by proton beams with photon IMRT beams to allow uniform coverage of the PTV.

Material and methods: The FLASH effect occurs when healthy tissue is irradiated with a minimum dose of 6 Gy and a minimum dose rate 40 Gy/s. To achieve these conditions, we used matRad, an open-source code implemented using Matlab by the German Cancer Research Center (DKFZ), which allows for multi-particle or photon treatment planning. For our strategy, we divided the PTV into different regions, which we called patch regions. For a patch region close to an OAR, a proton FLASH beam is used to deliver radiation dose. While for the remaining PTV volume, photon IMRT beams are used to deposit the necessary dose to achieve tumor coverage. All regions were optimized for both dose and dose rate. Furthermore, we also studied the robustness of our new multi-beam FLASH strategy to systematic and random shifts.

Results: We were able to irradiate the OAR's with a minimum dose of 6 to 10 Gy and dose rate above 40 Gy/s, which allowed for FLASH protection of the OAR. For the remaining PTV we were able to obtain $V_{(\text{prescribed dose})} \approx 95\%$; $D_{98} \gtrsim 0.95 * (\text{prescribed dose})$; $D_2 \lesssim 1.07 * (\text{prescribed dose})$; CI (conformity index) $\gtrsim 0.8$ and HI (homogeneity index) $\lesssim 0.1$. As a consequence, we delivered an uniform dose distribution to the whole PTV with the help of IMRT dose distribution patched with FLASH proton dose distribution. For the robustness analysis we found that the dose delivered to the CTV was not affected by systematic and random shifts.

Conclusions: We concluded from the obtained results that the novel strategy is suited for multi-beam FLASH radiotherapy. This patching approach allows us to achieve FLASH protection of the OARs without affecting the PTV dose coverage. In addition, we showed that our approach was robust to shifts of the CTV.

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EFOMP MPE STATUS AND THE ROAD TO NO BORDERS ACROSS OUR PROFESSION

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Medical Physics is a health profession where physical principles are applied in medicine for the benefit of patient care, both concerning efficacy and efficiency of diagnosis and treatment. The key role of the Medical Physics Expert (MPE) in safe and effective use of ionising radiation in medicine is widely recognised in European reference documents like the EU Council Directive 2013/59/EURATOM (2014), and European Commission Radiation Protection No. 174, European Guidelines on Medical Physics Expert (2014).

One of the most common queries to the Professional Matters Committee regards the acceptance of a Medical Physics Expert (MPE) certificate in one European country if an MPE certificate was already obtained in another European country? Unfortunately, there is no automatic recognition of MPE certification between European Countries since the role of Medical Physics Expert is not one of the professions recognised by the European Union (EU) in Directive 2005/36/EC which enables the free movement of professionals such as doctors or nurses within the EU. EFOMP wants to change that but in order to do this we need to ensure harmonisation of education and training of MPEs across Europe in order to guarantee the competencies of the certified MPEs. The first step to ensure harmonisation is the approval of the national registration schemes (NRS) for MPEs in each National Member Organisation (NMO), according to the eight criteria as detailed in the EFOMP document on NRS approval. This is a difficult process since each NMO has their own criteria for education and training but with the publication of RP174 and our core curriculums, EFOMP hope that each NMO will endeavour to ensure each MPE in their country is trained to the same level across Europe.

This talk will give a summary of work underway by EFOMP to make this a reality. Seven NMOs have their NRS approved by EFOMP

which brings EFOMP closer to recognise and protect the title of MPE and establish MPEs as a profession recognised by EU in Directive 2005/36/EC. This can only benefit our profession by allowing MPEs to transfer their qualifications and skills between NMOs and prevent unqualified personnel from using the title MPE

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APPLICATIONS OF A NOVEL CONTRAST AGENT IN X-RAY IMAGING OF ARTICULAR CARTILAGE: A PRELIMINARY EXPERIENCE

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Purpose: Contrast-enhanced computed tomography offers great potential for articular cartilage visualization, thanks to its high spatial resolution and the use of radio-opaque contrast agents. Recently a novel iodine-based cationic contrast agent CA4+, expected to interact electrostatically with negatively-charged proteoglycans within the cartilage, was proposed. Aim of this study is preliminary assessment of CA4+ spatial distribution in ex vivo bovine samples, at millimeter and sub-millimeter scale.

Material and methods: Sub-millimeter scale investigation was conducted on osteochondral plugs (N=18), extracted from tibial and femoral distal ends of bovine stifle joints (n=2). The samples were immersed in CA4+ solution at fixed concentration up to 26 hours, and planar images were acquired using a micro-computed tomography apparatus, at different time points. The CA4+ distribution inside the cartilage and the time required to reach 95% of maximum attenuation were evaluated.

After diffusion time was investigated, millimeter scale assessments were performed using a clinical computed tomography apparatus on distal-end tibiae of bovine stifle joints (N=3). After baseline acquisitions were obtained, the samples were immersed in CA4+ baths at different concentrations (5, 10, 15mgI/ml) up to 24 hours and imaged.

No animals were sacrificed for the aims of this work.

Results: The distribution of contrast medium, at sub-millimeter scale, differentiates into three distinct layers inside the cartilage – superficial, mid and deep layer. Such distinction is much apparent as the diffusion time increases. The depth-wise gradient should reflect the spatial distribution of proteoglycans, by which CA4+ molecules are electrostatically attracted. After 24-h diffusion, the iodine concentration reached in cartilage is approximately seven times the CA4+ bath, for both femoral and tibial samples. Nearly the same depth-wise distribution is observed between 6-hour and 24-hour diffusion time, as saturation is supposedly reached. The saturation time is τF95%=2.61±0.83h and τT95%=3.14±2.39h, for femoral and tibial samples respectively.

Millimeter scale analysis with computed tomography confirms overall contrast enhancement of cartilage after 24-hours immersion, observed for each contrast medium concentration. Distinct contrast enhancement is reached in different cartilage regions, depending on tissue's local features. Attenuation is observed to increase at higher contrast medium concentration baths (ΔC5=463HU±11HU, ΔC10=517HU±13HU, ΔC15=620HU±6HU).

Conclusions: CA4+ contrast agent significantly improves cartilage visualization. Its specific interaction with targeted constituents allows qualitative evaluation of cartilage state. The adoption of reference assessments (i.e. histology) may enable quantitative measurements of cartilage constituents and features. CA4+ use could be extended to non-destructive imaging of bio-engineered samples. Further investigations in pre-clinical field will be conducted.

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HELIUM-BEAM RADIOGRAPHY (αRAD): IMAGING OF AN ANTHROPOMORPHIC PELVIS PHANTOM USING ENERGY PAINTING

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Purpose: Compared to conventional photon-beam radiotherapy, ion-beam radiotherapy offers the potential of a more conformal dose distribution. As a characteristic of ion-beam radiotherapy, steep dose gradients enable focusing the dose in the tumor volume, but also increases the susceptibility to uncertainties. Therefore, a mitigation of uncertainties is of great interest. Sharing the physical mechanisms of ion-beam radiotherapy, low-dose helium-beam radiography (αRAD) can precisely measure the integrated relative stopping power along the beam axis, called water-equivalent thickness (WET). As a potential complement to patient-positioning X-rays, αRAD could verify the WET map with the planning X-ray CT before each treatment fraction.

Material and methods: Our detection system consists of three pairs of thin silicon pixel detectors (WET<0.8mm), which are aligned along the beam direction. The first two pairs provide path information of single ion, the last pair measures the energy deposition (dE) of each ion after traversing the object.

To make quantitative measurements of WET feasible, calibration curves were established to describe the relationship between dE and WET. However, the detection system bears the challenge of a narrow WET window, in which high-precision WET measurements are possible. Thus, the "energy painting" method was introduced, where measurements in multiple small subregions with optimized initial beam energies are performed.

Finally, the image quality was evaluated with polymethyl methacrylate (PMMA) phantom of well-known WET distribution, containing expected WETs for lateral projections of abdominal or pelvic sites. Furthermore, a first helium-beam radiograph of an anthropomorphic pelvis phantom was conducted to mimic an envisaged clinical application.

To accommodate the high WET values of the phantom, helium-beam energies of up to 239.5MeV/u were used, which are above the therapeutic range at the Heidelberg Ion-Beam Therapy Center (HIT).

Results: The spatial resolution of the presented αRAD for the PMMA phantom was determined to be 0.49 ±0.03lp/mm at WET values of ~290mm. The WET accuracy is quantified by the mean absolute percentage difference (MAPD) between the αRAD and a

reference based on range-pullback measurements. It was found to be as low as 0.21%. Furthermore, the acquisition of an αRad of the anthropomorphic pelvis phantom based on energy painting was successful.

Conclusions: The presented αRads of high-WET objects (280mm to 300mm) provide a WET accuracy/precision and a spatial resolution that have potential for an envisaged clinical application. The successful acquisition of a helium-beam radiograph of an anthropomorphic pelvis phantom confirms this finding regarding the capability to image complex objects.

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IDENTIFICATION OF INTRA-PROSTATIC LESIONS USING PSMA, ACETATE-PET AND MPMRI

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Purpose: Radiotherapy is a commonly used treatment method for patients with high-risk prostate cancer. Emerging evidence shows a benefit of increasing the dose to the dominant intra-prostatic lesion. In this study we examined the performance of ^{68}Ga-PSMA-11 PET, ^{11}C-Acetate PET/CT and mpMRI for identification of intra-prostatic lesions in patients with intermediate and high-risk prostate cancer, using whole-mount histopathology as reference standard, stratified by Gleason score.

Material and methods: 55 study participants with intermediate to high-risk prostate cancer planned for radical prostatectomy were included. ^{68}Ga-PSMA-11 PET/mpMRI and ^{11}C-Acetate PET/CT examinations were performed prior to surgery. After excision, the specimen was placed in a custom-made mold to prevent deformation and ex-vivo T2w MRI was performed. The specimen was fixed in formalin at least 24 h prior to slicing into 5 mm thick slices from apex to base. Standard histopathology procedures including paraffin embedding and microtoming in 5 µm thick slices were performed. Each slice was stained with hematoxylin and eosin and examined by the pathologist, who segmented and graded tumor foci. The slices were registered to the in-vivo images using the software MICE toolkit, resulting in an uncertainty of below 2 mm. Two radiologists and two nuclear medicine specialists examined the image data in a blinded manner and reported the findings according to PI-RADS v2.1 and E-PSMA guidelines, respectively. The sensitivity for detection was determined, stratified by Gleason score and lesion volume.

Results: The histopathological evaluation found 123 lesions > 0.05 cc, 85 lesions > 0.1 cc and 44 lesions > 0.5 cc. The Gleason score distribution was 16% (3+3), 21% (3+4), 21% (4+3), 35% (4+4) and 7% (>4+4). The mean sensitivities of detecting lesions with a Gleason score ≥ 3+4 and/or a volume > 0.5 cc (90 in total) were 19% (Acetate-PET), 42% (mpMRI) and 44% (PSMA-PET). 55 (61%) lesions in this group were identified by either mpMRI, PSMA or both. The histopathological examination identified 43 lesions with a Gleason score ≥ 3+4 and a volume > 0.5 cc. The mean sensitivities for this group were 36% (Acetate-PET), 69% (PSMA-PET) and 73% (mpMRI). 40 (93%) lesions in this group were identified by either mpMRI, PSMA or both.

Conclusions: The degree of detection increases with increasing Gleason score and lesion volume. PSMA and MRI generates high detectability, but they do not always detect the same lesions, which may indicate the value of a combined PSMA-PET/MRI examination.

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HIGH-PERFORMANCE CELLULAR RADIOSENSITIVITY ASSAY COMBINED TO A POLYGENIC SCORE TO PREDICT LATE POST RADIOTHERAPY OVERREACTION IN CANCER PROSTATE PATIENTS: A PROOF OF CONCEPT

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Purpose: Radioinduced toxicity is a multifactorial problem, related not only to the delivered dose, but also to intrinsic processes within tissues responding to cellular injury. Recently, a novel polygenic-risk-score (PRS) that for the first time incorporates Single-Nucleotide-Polymorphism (SNP)-SNP interactions was shown to be able to predict late toxicities in the REQUITE prostate cancer cohort (Franco RO2021). On the other way, recent studies have stressed the role of ATM-protein in the response to radiation on lymphocytes from blood and skin fibroblasts (Pereira IJROBP2018, Deneuve Cancers2021) and have confirmed that ATM-protein is a relevant biomarker. Objective of this analysis was to evaluate and validate the prediction assay RadioDTect® (based on ATM-protein concentration, Deneuve Cancers2021) combined with SNPs towards gastrointestinal and genitourinary toxicities after radiotherapy for localized prostate cancer.

Material and methods: We considered 48 prostate cancer patients treated with exclusive radiotherapy (VMAT) at a single institution at 74-80Gy with conventional fractionation.

For all patients toxicity was prospectively scored before radiotherapy and every 6 months till 3 years after the radiotherapy end combining CTCAE scale and patient-reported questionnaires. The endpoint of this analysis was any (gastrointestinal OR genitourinay) grade≥2 toxicity at 3 years after radiotherapy.

Blood samples were prospectively collected at least 6 months after radiotherapy and used to have the RadioDTect® and extract germline DNA.

We tested a pool of 15 SNPs associated with late radiotherapy toxicity from the literature with uni- and multi-variate logistic analysis. We used the multivariable logistic regression predicted probabilities to compute a PRS (using z-standardization of the predicted probability).

We investigated the value of a possible RadioDTect®+PRS combined biomarker and compared it with the results from dosimetry-based toxicity prediction (including the maximum dose to the rectum and the bladder).

Results: 18/48 patients scored with any grade≥2 late toxicity.

Patients with grade≥2 late toxicity were classified using RadioDTect® with a previously determined cutoff of 57.8ng/mL with AUC=0.63 (p=0. 04). 3/15 SNPs from the literature confirmed their association with late toxicity (rs11122573 from Kerns JNatlCancerInst2020, rs2293054 and rs845552 from De Langhe RO2014). The PRS from these 3 SNPs predicted late toxicity with AUC=0.71 (p=0.01). Combining PRS and RadioDTect® led to an improvement of AUC of

7% (p=0.04, AUC=0.78). Adding dosimetric information improved AUC of 2% (p=0.5, AUC=0.8).
Conclusions: The results of this proof of concept allowed us to confirm that biological assays tested in a population of prostate cancer patients treated with VMAT overperformed existing models for toxicity prediction.

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ASSESSMENT OF WEDGE FILTER INFLUENCE ON PEAK SKIN DOSE CALCULATIONS IN INTERVENTIONAL CARDIOLOGY

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Purpose: Complex interventional cardiology procedures can potentially lead to high peak skin dose (PSD) and subsequent patient skin reaction. The use of wedge filters is common in such procedures to compensate for body curvature and attenuation differences between tissues (e.g. the lungs and heart). Numerous skin dose calculation (SDC) software packages, both commercial and open-source, have been developed to estimate skin dose. The aim of SDC software is to reproduce the dimensions, shape and position of the PSD region, however, most software assumes square and uniform irradiation fields when mapping dose. This may lead to inaccurate shape and dimension of the reported PSD region when wedge filters are used. The purpose of this work is to account for the effect that the presence of the wedges have on PSD estimation.
Materials and methods: An audit was performed on Radiation Dose Structured Report (RDSR) files of patients undergoing interventional cardiology procedures on a Philips Azurion Clarity IQ system. The system has two rectangular, brass, 1mm thick wedges which can rotate 360°. Wedge filter positional information was extracted to examine the frequency of use of the wedges and the distribution of spatial positioning of the wedges in the beam. A wedge correction algorithm was developed and implemented into an in-house PSD software program based on the results of this audit.
Skin dose maps were also obtained using Gafchromic® XR-SP2 film for a phantom undergoing the 3 clinical procedures specified by the Validation and Estimation of Radiation Skin Dose in Interventional Cardiology's (VERIDIC) project on PSD software validation. These procedures were performed without wedges and then repeated using the system's automatic wedge positioning. Software and measured dose maps were compared to assess the effect of the wedge filters on the distribution of dose and the PSD estimation for a cohort of high dose patient studies and VERIDIC phantom setups.
Results: The audit results show that the wedges are in use for 99% of X-ray events, covering between 0.1% and 46% of the beam area (11% on average). Each wedge attenuates the beam by 90% at 75kVp. VERIDIC suggests a maximum deviation in PSD estimation of at least 40%, excluding the use of wedges. The uncertainty associated with neglecting the wedge filter will be presented and discussed.
Conclusions: The VERIDIC project states that accounting for the use of wedge filters would improve SDC software dose mapping in interventional procedures. This work quantifies this improvement.

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DAILY ADAPTIVE RADIOTHERAPY FOR PATIENTS WITH HYPOFRACTIONATED PROSTATE CANCER USING MR-LINAC: INITIAL CLINICAL EXPERIENCES AND ASSESSMENT OF DELIVERED DOSES COMPARING MLCS OF TWO DIFFERENT GENERATIONS

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Purpose: This study purpose was to compare the performance of the Double Stack Multi Leaf Collimator generation 2 (High Speed DSMLC) respect to the DSMLC generation 1, both designed for a 6-Megavoltage Linac based MR-guided radiation therapy system in a 0.35T magnetic field.
Material and methods: From November 2019 to February 2022, a retrospective single centre study was performed on patients with prostate cancer treated at San Pietro Fatebenefratelli Hospital (Rome, IT). The focus was only on patients underwent to a hypofractionated (62 Gy at 3.1 Gy per fraction, 20 fractions) prescription, treated with Viewray MRIdian system (ViewRay Inc, Oakwood Village, OH). The DSMLC upgrade took place in February 2022 and the average leaves speed was taken from 1.5cm/s to 4.0cm/s.
For all patients we collected data for each replanned fraction. The analysis was performed on: fields number, segments number, monitor unit (MU), total delivery time, beam on time, MLC+gantry time, coverage factor (CVF), conformation number (CN), homogeneity index (HI), trends of organs at risk (OAR) constraints. Patients were divided according to the year of the treatment.
Results: A total of 125 patients were included in the study, with a median of (76±9) years. Currently the total number of replanning is 876 (on going), so each patient was replanned a median of 6(IQR:4-10). At the moment we analysed 57 replanned fractions. The increased leaves speed allowed us to increase the number of the fields (from 7 in 2020 to 15 in 2022) and the segments (from 57±4 to 75±9), improving the CF (from 0.87±0.02 to 0.97±0.2), CN (from 0.86±0.03 to 0.89±0.05) and HI (from 0.22±0.04 to 0.15±0.08). All this leaving the total delivery time comparable (from 7.6±0.5 min to 8.1±0.7 min), such as the beam on time (from 71±2 min to 67±2 min) and the MLC+gantry time (from 28±2% to 43±25%). MU increased (from 934±98 to 1160±220). In these years the constraints OARs trends have been decreasing: for example about the bladder, our references were 47%<38.75Gy and 36%<54.25Gy. We started from 40±9% to 18±9% for the first constraint, and from 17±6% to 7±3% for the second one.
Conclusions: These results are partials, but they have already shown a better performance of the High Speed DSMLC compared to the previous one. Treatment plans are better both from geometric and dosimetric point of view. In future we are going to increase the numbers of patients analysed with the new DSMLC.

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HOW TO DEVELOP A VIRTUAL TOUR IN MEDICAL PHYSICS

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Purpose: For several years, virtual and blended-learning courses in Medical Physics are offered at the German Cancer Research Center (DKFZ) for national and international postgraduates, working in clinical or research institutes at the same time.
While hosting such courses, we were able to gain a deeper understanding of multimedia learning for working professionals and their specific needs. Based on this long-lasting experience, we could transfer all courses into a full virtual mode since the start of the Covid-19 pandemic. However, visits to Heidelberg and our clinical institutes were and still are not possible. Therefore, participants are lacking this important experience.
Material and methods: To fulfil this gap, we decided to develop a first virtual tour about our division Medical Physics in Radiation Oncology, based on previous work of the Austrian authors (e.g. developing virtual labs for students). The idea is to evaluate the workload, technical challenges and possibilities that are available to us for future tours.
As theoretical context we understand "multimedia learning" as "learning from words and pictures" (Mayer 2008, p. 761). Thus, it follows two channels: auditory/verbal and visual/pictorial. Both channels are limited and can only process a limited number of simultaneous processes (elaborated as Cognitive Load Theory by Sweller 2005). Main criteria derived from this framework are the basis for developing the tour layout (Mayer & Moreno 2003).
To develop the tour we decided to use existing tools like our Moodle platform which includes the H5P plugin and allows us to design virtual tours based on 360-degree pictures. In addition to existing audio-video equipment, we purchased a simple 360-degree camera.
Results: We are going to present the virtual tour and its layout and design, consisting of 360-degree pictures, text and videos offering an overview about our division at DKFZ.
Conclusion: The tour is considered as template for tours to be developed in the future. More work about the application of didactical criteria and about the user's perspective is needed to integrate virtual tours in didactical settings.
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CONVERSION FACTORS BETWEEN KERMA-AREA PRODUCT AND EFFECTIVE/ORGAN DOSE FOR CARDIAC INTERVENTIONAL FLUOROSCOPY PROCEDURES

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Purpose: The aim of this study is to lead a critical appraisal of the evidence concerning the conversion factors between kerma-area product (PKA) and effective/organ dose (DCED_PKA, DCHT_PKA) for cardiac interventional fluoroscopy procedures performed in adults and paediatric patients and to propose reference conversion factors to help standardize dose calculations.
Methods: A systematic review of the published literature was lead with a time restriction (since January 2007) to capture the evolving trends of utilization of fluoroscopy-guided intervention technologies only in recent years. The suggested DCED_PKA and DCHT_PKA were synthesized by calculating the weighted averages of the values reported by the authors with weights corresponding to the study sample size.
Results: Eighteen studies for both adult (9) and paediatric (9) patients matching the search terms fulfilled the inclusion criteria. The suggested value for DCED_PKA in adult patients amounts to 0.24 mSvGy-1cm-2. The suggested values for DCHT_PKA ranged from a minimum of 0.15 mSvGy-1cm-2 for the female breast to a maximum of 0.97 mSvGy-1cm-2 for the lungs. The suggested values for DCED_PKA in paediatric patients ranged from 3.45 mSvGy-1cm-2 for the new-born to 0.49 mSvGy-1cm-2 in the 15-years age class.
The suggested values for DCHT_PKA ranged from a minimum of 0.33 mSvGy-1cm-2 for bone marrow in the 15-years age class to a maximum of 11.49 mSvGy-1cm-2 for the heart in the new-born.
Discussion: The value of 0.24 mSvGy-1cm-2 for DCED_PKA in adult patients is consistently higher than the most often quoted value of 0.18 mSv Gy-1 cm-2. The increase in DCED_PKA can be partially explained by the changes in the tissue weighting factors between ICRP 103 and ICRP 60 and by the different X-ray beam quality used in modern angiographic equipment with respect to older machines equipped with image intensifiers.
The values obtained of DCED_PKA can be useful for standardizing dose calculations, hence for comparison of the radiation detriment from different imaging procedures. Having a reliable set of DCHT_PKA could prove to be very useful in the framework of epidemiologic studies.

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PATIENT SIZE CONVERSION FACTORS FOR CT DOSIMETRY COMPARED BETWEEN THE RDSR AND AN INDEPENDENT DOSE MONITORING PLATFORM

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Purpose: To assess reproducibility of size-specific conversion factors across calculation methods and platforms.
Material and methods: Data was collected from CT chest and CT abdomen examinations performed over 4 months on a photon counting CT (NAEOTOM Alpha, Siemens) at the university hospital of Leuven. In this scanner, patient size-specific information, i.e. the water equivalent diameter (WED) and the effective diameter (ED), is made available in the radiation dose structured report (RDSR). In parallel to this, a dose monitoring system (DOSE, Qaelum NV, Belgium) calculates the data from both the localizer and the slice images.
WED per slice and the WED as calculated from the localizer were collected from the RDSR and from DOSE. DOSE provided also an ED calculated from both the slices and the localizer. The corresponding size-specific conversion factors from CTDI to size-specific dose estimates (SSDE), i.e. the f-factors, were determined using the tables of The American Association of Physicists in Medicine (AAPM) reports 204 and 220. The size-specific descriptors of all the slices were used to determine an average size-specific factor and a standard deviation (SD) per patient. The f-factors based on WED and ED were compared and the intra-class correlation (ICC) coefficient

was calculated to asses agreement of different calculation methods and platforms.
Results: The agreement of the two platforms for the f-factor is highest when using the WED per slice (ICC = 0.98). The agreement is lower when calculating the WED based f-factor from the localizer (ICC = 0.76). However, for all patients, all f-factors calculated from the WED per slice are within 1 SD for both platforms. In 75% of the cases the f-factor calculated from the localizer based on ED (with DOSE) is outside 1 SD of the other calculation methods.
Conclusions: Trustworthy size-specific conversion factors are available on the newest scanners and in dose monitoring platforms. The most reliable method to determine a size-specific conversion factor is based on the WED per slice.

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DOSIMETRIC CHARACTERISATION OF ELECTRON FLASH BEAMS PRODUCED USING A MODIFIED ELEKTA PRECISE LINEAR ACCELERATOR

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Objective: This study aimed to investigate the dosimetric characteristics of electron fields produced by an Elekta Precise linear accelerator modified in-house with a view to producing ultra-high dose rate FLASH beams. A combination of experimental measurements and Monte Carlo (MC) simulations were used to determine the dose per pulse (DPP) and dose rates that can be achieved using this modified system and to examine the response of a range of different detectors with increasing dose rates to establish the most suitable detector for electron FLASH beam measurements.
Materials and methods: A MC model of an Elekta LINAC operating in conventional EBRT electron beam mode was developed using EGSnrc/BEAMnrc. Simulated percentage depth dose (PDD) and beam profiles were validated against measurement for three high electron beam energies under standard conditions using a PTW Advanced Markus ionisation chamber and E-diode detector, respectively. The reference detector is Gafchromic EBT XD film for both modes. The relative increase in DPP was then used to scale up the DPP computed by simulation using the MC model for conventional EBRT to obtain the values expected when operating in the FLASH mode. The simulation explored the effect of removing one or two of the scattering foils and reducing the SSD on DPP to demonstrate the possibility of achieving FLASH beams. The response of different detectors to increasingly higher dose rates when operating in the FLASH mode was investigated, and the results compared with those predicted by simulation.
Results: MC-simulated PDD and beam profiles were found to be in good agreement with measurements, and gamma analysis showing no significant differences between them, with pass rates of >95% using 2%/2 mm criteria. The simulations suggest that removing the scattering foils will enable the FLASH beam (>40 Gy/s) to be achieved at isocentre. The DPP variation as a function of SSD from 54 to 150 cm gives 0.2 to 0.025 cGy/pulse in EBRT, while 17 to 2 cGy/pulse in FLASH-RT, respectively. For conventional EBRT, measurements carried out with the Advanced Markus and a plastic scintillation detector were in good agreement with those from film and MC simulation. In FLASH mode, differences of up to ±13% were noted for the Advanced Markus ionisation chamber.
Conclusion: The model shows good agreements between measured and calculated data for both radiotherapy modes. The model can be used to validate various ranges of dosimetry detectors against FLASH irradiation in terms of dose, dose rate and DPP dependences.

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THE TIMING OF TREATMENT FRACTIONS IN RADIOIMMUNOTHERAPY COULD DETERMINE THE OUTCOME – A MODELLING STUDY

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Purpose: The combination of radiotherapy and the administration of immunogenic drugs to enhance the anti-tumour response from the immune system is currently the focus of numerous research projects. While the radiation itself is likely to stimulate an immune response contributing to the effectiveness of the treatment, adjuvant immunotherapy has the potential to significantly increase local control rates. However, the way in which the two treatment modalities should be combined is far from obvious. One of the biggest challenges is the timing of the immunotherapy relative to the radiotherapy, which could impact substantially on the resulting overall effectiveness of the treatment. This becomes particularly challenging in fractionated radiotherapy, given the added option to interlace the two treatment modalities in comparison to single-fraction radiotherapy. For hypoxic tumours, fractionation is known to impact substantially on the effectiveness of radiotherapy resulting from reoxygenation. It was the purpose of this modelling study to investigate the impact from the timing of treatment fractions in radioimmunotherapy on the treatment outcome of tumours with hetereogeneous oxygenation.
Material and methods: A three-dimensional in silico model of heterogeneous and dynamic tumour oxygenation was used to simulate hypoxic tumours undergoing radioimmunotherapy. Different assumptions were made for the timing of the immunotherapy with respect to the radiotherapy, and a modified linear-quadratic model including the effect of immunotherapy based on the evolution of the number of tumour infiltrating immune effector cells and the number of antigen molecules during the treatment was used to calculate the surviving fraction on voxel level. A Poisson-based model for tumour control probability based on the surviving fraction on voxel level was used to assess the tumour response to the treatment, also accounting for the voxelised modification of radiosensitivity resulting from the heterogeneous tumour oxygenation.
Results: For a tumour with 10% hypoxia, the TCP after a dose of 20 Gy delivered in four fractions and followed by four fractions of immunotherapy was 38%. If the immunotherapy fractions were instead interlaced with the radiotherapy fractions, the resulting TCP ranged from 21% to 92% depending on the assumed evolution of the number of tumour infiltrating immune effector cells and the number of antigen molecules.
Conclusions: While radioimmunotherapy is likely to enable increased rates of local control, the temporal distribution of immunotherapy fractions in relation to the radiation could determine the outcome of the treatment and should therefore be more extensively studied.

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COMPARISON OF PATIENT-DELIVERED RADIATION DOSES DURING CONE-BEAM CT- AND INTRAOPERATIVE CT-BASED SPINAL NAVIGATION

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Purpose: To estimate the radiation dose delivered to patients undergoing navigated posterior spinal instrumentation across the entire spine using cone-beam computerized tomography- (CBCT) and intraoperative fan-beam computerized tomography (iCT)-based spinal navigation.
Material and methods: Dose data from 235 patients was retrospectively exported from the dose management system (DoseM, Infinitt). Between February 2021 to February 2022, all patients underwent navigated posterior pedicle screw instrumentation for treatment of spinal instabilities at our institution. 145 patients were operated using Artis Zeego robotic CBCT: Here, 2 CBCT protocols – 6sDCT (standard protocol) and 10sDCT (low dose protocol) – were used. 90 patients were operated using the mobile AIRO iCT utilising the given protocols for different scan regions. The following scan regions were studied, for CBCT and AIRO CT: cervical spine, cervical-thoracic spine, thoracic spine, thoracic-lumbar spine, lumbar spine, and lumbar-sacral spine. We compared the delivered mean effective dose ($\bar{D}eff$) for each body region and imaging modality, respectively. The iCT $\bar{D}eff$ values were estimated from the patients' dose length product (DLP) using conversion factors k published in ICRP 103. The CBCT $\bar{D}eff$ values were estimated using a Monte Carlo program for calculating patient doses in medical X-ray examinations (PCXMC 2.0, STUK).
Results: The estimated $\bar{D}eff$ for scans in the cervical-thoracic (21.9 and 19.9 mSv), thoracic-lumbar (46.4 and 24.9 mSv) and lumbar spine (40.7 and 29.2 mSv) were higher using both the standard- and low-dose CBCT protocols than the corresponding $\bar{D}eff$ for iCT scans (cervical- thoracic 11.0 mSV; thoracic-lumbar 15.2 mSv; lumbar: 14.8 mSV). In contrast, $\bar{D}eff$ for the cervical (4.6 mSv) and thoracic spine (20.4 mSv) using the standard-dose CBCT protocol were comparable to $\bar{D}eff$ from corresponding iCT scans (cervical 4.6mSv; thoracic 20.2 mSV). In the lumbar-sacral region $\bar{D}eff$ with standard-dose CBCT (47.0 mSv) and iCT (29.5 mSv) was higher than $\bar{D}eff$ from low-dose CBCT (24.0 mSv).
Conclusion: Between similar anatomic regions, the mean effective dose delivered to the patient was generally higher for CBCT than for iCT imaging. Importantly, the mean effective dose from CBCT low-dose protocols was significantly reduced compared to the CBCT high-dose protocols, which underlines the importance of optimizing and establishing low-dose scan protocols before routine application of CBCT imaging in spinal navigation.

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PRE-CLINICAL CHARACTERISATION OF OPTICAL FIBRE SENSORS IN HDR BRACHYTHERAPY

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Purpose: To characterise optical fibre sensors, developed as part of the EU funded H2020 project "ORIGIN", using an Iridium-192 (192Ir) HDR brachytherapy source in a pre-clinical setting in preparation for use in adaptive brachytherapy.
Materials and methods: Three optical fibre prototypes connected to scintillation detectors were used to undertake measurements on an Elekta Flexitron HDR system. Initial measurements were performed by placing each fibre in turn within a HDR prostate Perspex needle phantom capable of holding 20 HDR needles in parallel, placed between two solid water blocks. The fibre was placed within a plastic HDR needle catheter inserted in a central channel within the phantom and the 192Ir source was inserted to maximal depth within separate HDR catheters, placed in line with the scintillating tip of the fibre at 1 cm, 3 cm and 5 cm distances in turn, for a dwell time of 10 seconds. Measurements were performed four times without altering the setup to assess repeatability. Additional source to fibre distance measurements were separately taken using one fibre placed within a brachytherapy catheter containing an internal polytetrafluoroethylene (PTFE) tube to reduce positional uncertainty of the fibre tip further. The scintillating fibre tip was exposed to the 192Ir source at increasing distances from 1 cm to 10 cm. Measurements were repeated three times and photon count rates corresponding to each distance were averaged. These count rates were then compared to absolute dose calculations from the Oncentra Brachytherapy (v4.6.1) treatment planning system, normalised to 3 cm.
Results: Variability in terms of repeatability measurements ranged from 0.22%-1.58% at 1 cm distance, 0.18%-0.74% at 3 cm and 0.35%-0.85% at 5 cm from the 192Ir source. The fibres demonstrated linear dose-response relationships with all calculated coefficients of determination > 0.99. When normalised to 3 cm it was found that the fibres under responded at distances close to the source and over responded at distances further from the source, or vice versa.
Conclusions: The optical fibre sensors demonstrated linear dose-response relationships with < 1% variability in repeatability measurements at distances ≥ 3 cm from the 192Ir source. The difference in output at increasing distances from the 192Ir source compared with the treatment planning system indicates the need for exploration of the fibre sensors' energy dependence and the calculation of a correction factor.

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A STUDY OF DENSITY ADJUSTED 3D PRINTING FOR THE MANUFACTURE OF SOFT TISSUE EQUIVALENT COMPUTED TOMOGRAPHY PHANTOMS

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Purpose: In the recent years, 3D printing technology is replacing the conventional methods used for the manufacture of radiologic phantoms. In this study, it is aimed to investigate the usefulness of new kind of 3D printing filaments whose density can be adjusted by modifying printing parameters such as printing temperature and flow rate.
Materials and methods: Two different 3D printing filaments (Low Weight PLA and Varioshore TPU, ColorFabb) and two different 3D

printers (Ultimaker 3 Extended and Crealty Ender 3 Pro) were used to print cylindrical samples with 1.5 cm diameter and 2 cm height. PLA samples were printed at temperatures between 200oC and 220oC and flow rates between 100% and 80% while TPU samples were printed at temperatures between 190oC and 200oC and flow rates between 115% and 85%. Infill rates were held constant at 100% for all samples. Mass of the samples were measured by using a balance scale (SI-234, Denver Instrument) to determine their densities prior to computed tomography (Ingenuity 128-DS, Philips) scan. All samples were located within a PMMA cylinder filled with distilled water. Computed tomography scan was performed at a tube voltage of 120 kVp. Mean Hounsfield Unit values and standard deviation of these values were recorded at 10 different axial positions for each sample with the use of 1 cm2 circular region of interest.
Results: Physical densities were recorded between 0.93 gr/cm3 and 1.23 gr/cm3 for PLA samples and 0.75 gr/cm3 and 1.1 gr/cm3 for TPU samples. Mean Hounsfield Unit values of PLA samples printed by both 3D printers ranged approximately between -200 HU and +135 HU, while the minimum and maximum standard deviation values observed for these samples were 8 HU and 14 HU, respectively. On the other hand, mean Hounsfield Unit values of TPU samples printed by both 3D printers ranged approximately between -360 HU and +20 HU, while the minimum and maximum standard deviation values observed for these samples were 7 HU and 15 HU, respectively.
Conclusions: Findings of our study showed that it is possible to obtain reasonably homogeneous 3D printed samples that are radiologically equivalent to most of the soft tissues by using only one type of filament, rather than different filaments with different densities, provided that its density can be adjusted by modifying printing parameters such as printing temperature and flow rate.

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QUANTIFICATION OF INCIDENTAL CLINICAL TARGET VOLUME COVERAGE IN LINEAR ACCELERATOR BASED LUNG SABR

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Objective: The aim of this study is to assess incidental CTV coverage in SABR plans as a function of prescription dose, motion and volume.
Methods: Retrospective review of 30 lung cancer cases treated with LINAC based SABR utilising coplanar VMAT. To assess CTV coverage in static motion cases as we acquired linear distance measurements from the GTV edge to the 50Gy Equivalent Dose in 2Gy per fraction (50Gy EQD2) centrally in the axial plane and in the coronal plane for prescriptions ranging from 105Gy to 151Gy BED10. To assess impact of motion on CTV coverage in the cranio-caudal (cc) direction, D99% data of CTV time weighted sub-volumes of individualised phase datasets were compared to the lowest D99% of each sub-volume. To assess impact of PTV volume on CTV coverage as a function of prescription dose, GTV edge to the 50Gy EQD2 was plotted as a function of volume.
Results: For static cases, mean distance from GTV edge to 50Gy EQD2 at central axial tumour slice ranged from 13.4mm±2.0 for BED10 105Gy to 18.2mm±1.8 for BED10 151Gy and from 8.3±1.2mm for BED10 105Gy to 9.5±1.2mm for BED10 151Gy in cc direction. For motion cases, the maximum increase in D99% for the most superior and inferior sub-volumes went from 9.8% (range 7.0%-15.7%) for tumours with motion of 0.5-1.0 cm to 18.1% (range 9.25%-37.2%) for tumours moving from 1.0cm to 2.0cm. A trend of increasing mean distance from GTV to 50Gy EQD2 with increasing PTV volume was observed.
Conclusion: Incidental CTV coverage is adequate with linac based VMAT SABR using 5mm PTV margins. Any reduction in this PTV margin in the cc direction may compromise CTV coverage and increase marginal failures.

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ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS INCLUDING COMPLEXITY INDEX ANALYSIS IN CEREBRAL ANGIOGRAPHY PROCEDURES

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Purpose: Establishment of diagnostic reference levels (DRLs) in interventional radiology requires a comprehensive analysis regarding the complexity of the procedure which depends on lesion characteristics, disease severity and clinical practice and highly influences the patient dose. This study aims to propose typical DRLs including complexity index analysis for the cerebral angiography procedures carried out at the radiology department of our university hospital.
Materials and methods: Retrospective data collection has been carried out between January 2019-January 2022. All of the cerebral angiography procedures were performed with Phillips Allura Xper 20/10 biplane x-ray imaging system. Dataset involved dose area product (DAP), cumulative air Kerma at the reference point (Ka,r) and fluoroscopy time (FT). The study population was divided into 4 groups regarding the complexity of the procedures which has been analysed based on ease of access (easy/difficult) to the anatomic region of interest and the number of cerebral vessels (1, 2, 3 or more) being imaged during the intervention. DAP, (Ka,r) and FT data of 4 groups were statistically analysed using SPSS software. Median values of each dataset were recorded as typical DRLs representing the institutional practice with respect to different complexity indices.
Results: 141 patients have been included in this study 50% of which were male and 50% were female, with a mean age of 53 (±16). Group 1 patients (n=26) had 1 imaged vessel of easy access while 2nd group had either 1 imaged vessel with difficult access or 2 imaged vessels with easy access. Group 3 patients had either 2 imaged vessels with difficult access or 3 or more vessels with easy access. The 4th group of patients included patients with 3 or more imaged vessels with difficult access. Median DAP values were recorded as 34 Gy.cm2, 50 Gy.cm2, 69 Gy.cm2 and 103 Gy.cm2; median Ka,r values were recorded as 312 mGy, 391 mGy, 506 mGy and 687 mGy while median FT values were recorded as 118 sec, 202 sec, 265 sec and 471 sec for group 1, group 2, group 3 and group 4, respectively. Statistical analysis between the groups yielded significantly different results for all three parameters.
Conclusions: Our findings indicated that dose from cerebral angiography procedures depends on complexity of the procedure. This study is part of an institutional project which is supported by Dokuz Eylül University and aims to reach a more extensive database to cover local and national DRLs in the near future.

POSTER ABSTRACTS – AI

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IMPROVING THE PERFORMANCE OF MACHINE LEARNING MODELS THROUGH A MULTI-SITE MRI DATA HARMONIZATION FRAMEWORK

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Purpose: Multi-center data collections may suffer the batch effect, i.e. different scanners and/or acquisition protocols encode confounding information, which, especially in case of Magnetic Resonance Imaging (MRI) studies, should be curated to avoid confounding effects for ML classifiers and masking biases. This issue is particularly important when studying populations that are barely separable based on MRI data, such as subjects with autism spectrum disorders (ASD) versus controls with typical development (TD).
In this study, we show how the implementation of a harmonization framework on brain structural features improves the ability of case-control ML separation in the analysis of a multi-center MRI dataset.
Material and methods: We analyzed the structural MRI brain scans of ABIDE I and ABIDE II data collections. Specifically, we selected male subjects with ages between 6 and 40 years, consisting of 1645 subjects from 37 sites including 845 TD participants (mean age (M) =15.6 years, standard deviation (STD) = 7.0 years and age range (R) = [6.3-40]) and 793 subjects with ASD (M = 15.2 years, STD of age = 6.3 years and R = [6.4-40]).
To harmonize the dataset we used the NeuroHarmonize harmonization tools for multi-site neuroimaging (Pomponio et al., 2020). We estimated the harmonization model on the control group and then, we applied the model parameters on the group of ASD subjects to obtain a dataset entirely harmonized for site effects.
The case-control binary classification was carried out with a Random Forest (RF) classifier, whose performance was evaluated by computing the Area (AUC) under the Receiver Operating Characteristic (ROC) curve, estimated in 5-fold cross-validation. The performance of the RF binary classifiers was evaluated for the whole sample and the age-specific subgroups both in the case of non-harmonized (original) image features and on the harmonized ones and compared.
Finally, for the age-specific subgroups, we investigated which features had a strategic role in the classification.
Results: After data harmonization, the overall ASD vs. control ML discrimination performance improves from AUC = 0.58 +- 0.04 to AUC = 0.67 +- 0.03. In the age-specific subgroups, the performance improves on average by 23%.
The most important features for classification varied across age subgroups but also shared features across ages were identified, mainly in the fronto-temporal regions associated with social communication skills.
Conclusions: This study shows how the implementation of a harmonization protocol is a necessary preprocessing step in the analysis of brain descriptive features extracted by MRI scans in multi-center studies.

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CNNS AS MODEL OBSERVERS FOR LOW-CONTRAST DETECTION TASK IN CT

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Purpose: The optimization of Computed Tomography (CT) protocols is essential to fulfill the ALARA principle. Such optimization is achieved through the accurate assessment of the image quality as a function of radiation dose. This task is usually achieved by visual evaluation of specific reference images by medical staff. However, this procedure is quite time-consuming and onerous, and recently model observer (MO) algorithms have been proposed to predict the performance of human observer for overall image quality assessment. The purpose of this study was the development and evaluation of Convolutional Neural Networks (CNNs) as model observers for a low contrast signal detection and localization task in phantom CT images.
Material and methods: A large dataset of approximately 30000 CT images was collected on a specifically designed polymethylmethacrylate (PMMA) phantom, containing cylindrical inserts of different diameters filled with iodinated contrast media at two different concentrations: the phantom was repeatedly scanned on a clinical CT scanner at various CT Dose Index (CTDI) selecting the standard protocol for abdomen and the raw data were reconstructed with two different reconstruction algorithms. The full dataset was labeled by a group of radiologists who indicated, for each image, a confidence rating for signal presence or absence (an integer score from 0 to 3) and, in case of presumed presence, the location of the object within the image. Human-labeled data were used to train two different CNN architectures as model observers, to perform the double task of score prediction and object localization. For each insert size, contrast, reconstruction algorithm and CTDI level, the performance of trained CNN models was evaluated by comparing the area under the localization receiver operating characteristic curve (LAUC) obtained by CNN-MOs against the one obtained by human observers.
Results: CNN-MOs accurately predict the LAUCs of human observer even for smaller inserts (3 and 4 mm diameter), the ones showing the highest human performance deterioration at lower CTDI level. Different performance metrics were additionally computed to get insight into the behavior of the trained CNNs, showing a very good agreement with the image quality assessment criteria based on interpretation of radiologists.
Conclusions: Deep learning-based model observers, trained on a huge dataset of CT phantom images labeled by radiologists, have

shown excellent results in predicting human observer's performance in both detection and localization tasks: their application in the CT protocols optimization is a promising realistic alternative to the time-consuming human observer visual evaluations.

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DEEP LEARNING SEGMENTATION OF HEART SUBSTRUCTURES IN RADIOTHERAPY TREATMENT PLANNING

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Purpose: The mean heart dose is a risk factor for radiation-induced cardiac toxicities. However, knowledge of the local dose to each of the substructures of the heart will improve current predictions of cardiac toxicities. The main obstacle to this is that manual segmentation of these substructures in planning computed tomography (CT) is time consuming for radiation technologist and requires a lot of experience. We explored a deep learning algorithm for the segmentations of the substructures of the heart in CT.
Materials and methods: We used 180 delineated radiotherapy (RT) planning CT scans of lymphoma and lung cancer patients treated with RT at our institution. The annotated structures were the left and right ventricles (LV, RV), left and right atria (LA, RA), right coronary artery (RCA), left anterior descending artery (LAD), and the circumflex branch of the left coronary artery (CFLX). The dataset was split in a ratio: 7:1.5:1.5 for training, validation, and testing. We developed seven 2D UNet models by extracting 53 axial 129x129 slices for each patient, limited to the maximal cardiac border. To investigate hyperparameter selection, we compared four different loss functions during training: binary Dice score loss (BDS), binary cross-entropy loss (BCE), a binary focal loss (BFL), and an equally weighted sum of BDS and BCE. In addition, we masked the heart by removing all CT data outside the heart contour. We used the Dice score as the evaluation metric.
Results: In the major substructures, the ventricles and atria, mean Dice values above 80% were obtained (88% LV, 83% LA, 82% RA, 81% RV). For the small substructures, the best Dice score reached were 34% LAD, 20% CFLX, 16% RCA. The best results were generally obtained when masking was applied. The influence of the loss function shows different results for each substructure. While BCE and BDS lead to better results for the larger structures, for the RCA and the CFLX only the networks trained with BFL and weighting BDS/BCE were able to achieve a Dice score greater than zero.
Conclusions: When segmenting cardiac substructures, the choice of loss function is important. The combination of BDS/BCE as loss function works best for small substructures, whereas training with only BDS or BCE was not successful. BDS/BCE ratios different from 0.5/0.5 (0.3/0.7, 0.7/0.3) did not lead to better results. Improvements are needed for the smaller structures, which could be achieved by guiding the network based on additional data.

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CT-BASED RADIOMIC FEATURES AS PREDICTORS OF RESECTABILITY IN LOCALLY ADVANCED PANCREATIC CANCER TREATED WITH RISK ADAPTED ABLATIVE RADIATION THERAPY

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Purpose: The improved survival in locally advanced pancreatic cancer (LAPC) is mainly due to surgical resection after neoadjuvant treatment. However, diagnostic performance of computed tomography (CT) in restaging after neoadjuvant therapy is low. In this context, radiomics is gaining popularity for the possibility of decoding crucial information underneath medical imaging potentially serving in therapeutic decision-making process.
We explored the capability of radiomic features to predict surgical resection in LAPC treated with neoadjuvant chemo-radiotherapy.
Material and methods: Seventy-one patients with LAPC treated with chemo-radiotherapy were retrospectively reviewed. Radiotherapy(RT) was delivered considering BED10=100 Gy delivered following two schemes: stereotactic-ablative-RT (SAbR: 30 Gy/5 fractions to the PTV and 50 Gy SIB to vascular involvement), or hypo-fractionated-ablative-RT (HART: 50.4 Gy/28 fractions to the PTV, vascular SIB of 78.4 Gy)
The volume of interest (VOI) for radiomic analysis was delineated on planning-CT and corresponded to the gross tumour volume (GTV) excluding any potential source of artifact.
1655 radiomic features were extracted from the VOI using PyRadiomics. Both extracted features and clinical data (tumour location, size, pre and post-therapy cancer antigen 19-9 value, clinical stage, chemotherapy and radiation therapeutic regimen) were used to create and validate the predictive model of resectability status. Patients were repeatedly divided into training (70% of patients) and validation set. The capability to predict surgical resection was tested using Wilcoxon rank-sum test, removing correlated features (Pearson's r>0.9). The discriminating performance of each model, obtained applying multivariate and 5-fold cross-validation LASSO regression analysis to select relevant variables and build the model, was assessed with the area under the receiver operating characteristic curve (AUC). Finally, the validated model was applied to check the consistency of the selected features.
Results: Median age was 65 years and 57.8% of patients were male. All patients underwent chemotherapy followed by ablative radiotherapy, and 19 (26.8%) ultimately received surgical resection. After the first step of variable selections, a predictive model of resectability was developed with a median AUC for training and validation sets of 0.862 (95%CI: 0.792-0.921) and 0.853 (95%CI: 0.706-0.960) respectively. The validated model was applied to the entire dataset and 4 radiomic features were selected to build the model, with predictive performance as measured using AUC of 0.944 (95%CI: 0.892-0.996).
Conclusions: The present CT-radiomic model demonstrated a reliable performance to predict resectability in LAPC treated with chemotherapy followed by ablative RT. Radiomic information may complement clinical and morphological parameters in predicting surgical resectability.

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A MACHINE LEARNING APPROACH FOR PERSONALIZED DOSIMETRY PREDICTION IN PEDIATRIC NUCLEAR MEDICINE APPLICATIONS

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Purpose: Personalized dosimetry in pediatric patients is of great interest, due to the higher radiosensitivity that children experience

in comparison to adults. Artificial Intelligence developments in medical applications can serve towards the personalization of dosimetry protocols. The objective of this study is the design, development and evaluation of a machine learning model that predicts the dose rate per organ of interest in pediatric patients.

Material and methods: A previously developed realistic dosimetry database was utilized. The database includes simulated absorbed dose rates of 27 different organs in a pediatric population of computational phantoms. The GATE MC toolkit (v9.1) was used for the dosimetry simulations of several commonly used radiopharmaceuticals. For this specific application 99mTc-MDP was considered, together with its specified activity distribution in 28 voxelized pediatric models (virtual patients), with different anatomical characteristics and varying age, gender, mass, height and organs' sizes. The radiation activity of each organ derived from clinical data, at different time points (4 time points for Tc-99m were assumed: T=0h, T=1.42h, T=4.11h, T=20.2h), and was used for the dosimetry assessment.

For the development of a dosimetry predictive model, the effectiveness of several machine learning regression algorithms (Random Forest Regressor, XGBoost Regressor, Gradient Boosting Regressor, Decision Tree Regressor, Support Vector Regressor, Ridge Regression and Linear Regression) has been investigated. The ML models were trained using 9 anthropometric features as input: Age, Gender, Weight, Height, BMI, Anteroposterior thickness, Lateral width, Lung size and Effective diameter. Single and multiple organ input-output models, based on each ML algorithm, were trained, and validated using the Leave One Out cross validation method.

Results: The models with the most accurate predictions were based on Random Forest, Gradient Boosting and XGBoost regression algorithms and achieved Mean Absolute Percentage Error (MAPE): 8.207%, 8.286% and 9.438%, and coefficient of determination (R2): 0.971, 0.969 and 0.959 respectively. In all main organs of interest, the predictive model provided differences lower than 10% in terms of absorbed dose per organ. Larger differences were depicted in very small organs (eg. parathyroid).

Conclusions: Aiming at higher levels of predictive accuracy, extended investigation for the optimal combination of features for each model will be conducted, followed by hyper-parameter tuning. Ensemble learning techniques will be applied to combine the outputs of the primary models towards producing the final dosimetry prediction. The model will be applied in the whole dosimetry database.

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A NOVEL DIAGNOSIS AND SEVERITY PREDICTION ML-BASED MODEL: APPLICATION TO THE IDENTIFICATION AND PREDICTION OF COVID-19 FROM CT RADIOMIC FEATURES

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Purpose: Current study develops a two-steps ML-based model to diagnose and predict involvement of lungs in COVID-19 and pneumonia patients using CT chest radiomics features.

Methods: 300 CT scans (100 COVID-19, 100 pneumonia, and 100 healthy) were collected. Whole lungs were segmented utilizing DL-based segmentation method (COLI-Net). 107 features including shape, first-order histogram, texture, and second-order features were extracted using the 3D-Slicer tool followed by Pearson correlation coefficient (PCC≥90%) to exclude highly correlated features. Subsequently, 5 feature selection algorithms (CorrelationAttributionEval, InfoGainAttributionEval, WrapperSubsetEval, ReliefFAttributEval, and CfsSubsetEval) using WEKA (version 3.8.2) were assessed. The most pertinent features were finally selected using voting method based on the evaluation of all algorithms.

For the diagnosis task, datasets were randomly divided into 10% test sets and 90% training sets (70% and 30% for training and validation, respectively). Several ML-based supervised algorithms; Naïve Bays, Support Vector Machine, Bagging, Random Forest, K-nearest neighbors, Decision Tree and Ensemble Voting were utilized. The optimal model was selected based on precision, recall and AUC by randomizing the training/validation sets 20 times and then tested on the test set. To ensure the repeatability of the results, the entire process was repeated 50 times.

For severity prediction, two radiologists scored involvement of lungs in COVID-19 and Pneumonia scans based on percentage of involvement in all 5 lobes. Datasets were classified into mild (0-25%), moderate (26-50%), and severe (>50%). Datasets were randomly-divided into 10% test sets and 90% (70% and 30% for training and validation, respectively). The synthetic minority oversampling technique was used to balance the three classes. Training and validation were performed as mentioned in the diagnostic task.

Results: 9 pertinent features (2 shape, 1 first-order, and 6 second-order features) were obtained after dimensionally reduction and feature selection. Random Forest was found to be the best classification model. Precision, recall, F1-score, and AUC were 0.922±0.017, 0.922±0.057, 0.922±0.03, and 0.979±0.014, respectively. The performance of the three-class classification using Random Forest was 0.909±0.026, 0.907±0.056, 0.902±0.044, 0.939±0.031 and 0.982±0.010 for precision, recall, F1-score, accuracy and AUC, respectively. The severity prediction model using Random Forest correctly classified CT scans into mild, moderate, and severe with 0.868±0.123 precision, 0.865±0.121 recall, 0.853±0.139 F1-score, 0.934±0.024 accuracy, and 0.969±0.022 AUC.

Conclusion: The two-steps ML-based model accurately classified COVID-19 and pneumonia patients using CT radiomics, and adequately predicted their severity. This two-steps model showed great potential in assessing COVID-19 CT images towards improved management of patients.

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CLINICAL TRIAL QUALIFICATION OF PET-CT SCANNERS IN ONCO-HAEMATOLOGICAL CLINICAL TRIALS: A WORLDWIDE EXPERIENCE FROM CUNEO IMAGING CORELAB

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Purpose: The aim of this study was to describe the Clinical Trial Qualification(CTQ) program adopted by the ItalianFoundationOnLymphoma(FIL), the GrupoEspanolDeLinfomas/TransplanteAutologoDeMedulaOsea(GELTAMO), the InternationalExtranodalLymphomaStudyGroup(IELSG), the SwissGroupForClinicalCancerResearch(SAKK) and the PolishLymphomaResearchGroup(PLRG) through the Cuneo imaging corelab.

Material and methods: The CTQ consisted in the scanning two phantoms(Cylindrical Uniform-CUP) and NEMA/ACR image quality phantom-IQP) with the acquisition and reconstruction parameters used in clinical routine. Phantoms were filled with a 18F solution by medical physicists from the participating sites. Acquired images were transferred to Cuneo Corelab where were analysed checking that the image quality parameters were within the preset tolerance: background activity concentration (BAC) in the CUP,defined as the difference between the average activity concentration in a large homogenous region and the expected activity concentration below 10% and recovery curve (RC) (reconstructed using all the six hot spheres normalized to the activity concentration in the biggest sphere) within EARL limits and with a "smooth" shape). BAC was also measured I the IQP for reference. Inter-scanner variability (ISV) was estimated as the 95% confidence level of BAC-IQP.

IQP images reconstructed with all available algorithm (iterative and/or with TOF, resolution and noise modelling) were required in order to evaluate the difference in the RC in the new generation of PET/CT scanner.

Iteration to reach CTQ was defined as an interaction between the Cuneo Corelab and the local personnel regarding the data, phantom preparation, infrastructural problems.

Results 174/183(95%) PET/CT scanners fulfilled the CTQ process. CTQ was reached at the first round in 40% of the cases, while in 31%, 11% and 18%, two, three or more than three iterations, were required, respectively. The ISV for BACIQP was 50.9%. We observed an increase of recovery in images reconstructed with PFS: RC values the 17 and 22 mm diameter spheres for a sub-sample of 7 scanners were indeed 0.91(0.86-0.95) and 0.95(0.86-1.06) without and 1.05(1.01-1.09) and 0.99(0.92-1.08) with resolution recovery. Interestingly, in some cases RC values were larger than unity and the curve showed a non-regular trend in function of sphere diameter (roller-coaster shape).

Conclusion: The CTQ is a robust and reproducible procedure to verify inter-scanner calibration. A higher ISV in BAC-IQP respect to BAC-UP is observed demonstrating probably the fact that CUP, used to achieve CTQ, is more accurately prepared by local sites respect to IQP. Attention shall be devoted when reconstruction algorithms using resolution modelling is used, in particular for trial that require a quantitative analysis of PET images.

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EVALUATING HISTOGRAM AND TEXTURE CONTRIBUTION IN MACHINE LEARNING ANALYSIS OF MUSCLE ULTRASOUND IMAGING IN DIFFERENTIATING NEUROGENIC FROM MYOPATHIC DISEASE: A PILOT STUDY

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Purpose: Muscle ultrasound (MUS) has been proven a valuable tool for identifying abnormalities and tracking the progression of neuromuscular disorders. Differentiating between neurogenic and myopathic disease in MUS images can be demanding, especially in early or severely advanced stages of the pathology. The use of Machine Learning (ML) can provide useful clinical information towards differentiating disease characteristics. The objective of this study is to investigate the ability of differentiation between neurogenic, myopathic and healthy rectus femoris muscle, using histogram and texture analysis of MUS images.

Material and methods: B-mode ultrasound transverse images of the rectus femoris muscle of 24 patients diagnosed with Amyotrophic Lateral Sclerosis (ALS) (mean age 63.79±8.7 years, mean BMI 26.64±5.9 kg/m^2), and 24 patients diagnosed with muscular dystrophy (mean age 44.05±13.6 years, mean BMI 25.26±4.82 kg/m^2) were evaluated. The control group consisted of 41 sex-, age- and BMI-matched healthy subjects. 46 features were extracted, 14 of which were histogram (first-order) derived parameters and 32 texture (second and higher-order). A ML approach was used to assess the differentiating ability of the extracted features between neurogenic-healthy, myopathic-healthy, as well as neurogenic-myopathic groups. For this task Logistic Regression (LR), Random Forest (RF), and Support Vector Machine (SVM) classifiers were employed. The area under curve (AUC) of the receiver operating characteristic (ROC) curve was used to evaluate the classification performance.

Results: Analysis of the classification performance between the neurogenic and healthy groups revealed 19 features with AUC ≥0.70. The best performing features were histogram first quartile (Q1) (AUC=0.71) with the use of LR classifier and texture Gray-Level Run Length Matrix (GLRLM) Low Gray-level Run Emphasis (LGRE) (AUC=0.84) with the use of SVM classifier. Analysis of the classification performance between myopathic and healthy groups demonstrated 25 features with AUC ≥0.70. The best performing features were histogram Max (AUC=0.80) with the use of LR classifier and texture Neighborhood Gray-Level Difference Matrix (NGLDM) Coarseness (AUC=0.83) with LR classifier. Finally, analysis of the classification performance between neurogenic and myopathic groups resulted in 21 features with AUC ≥0.70. The best performing features were histogram Skewness (AUC=0.78) with SVM classifier and texture Grey-Level Co-occurrence Matrix (GLCM) Entropy_log10 (AUC=0.81) with LR classifier.

Conclusion: Results indicate that both histogram and texture features may contribute to the differentiation between neurogenic, myopathic and healthy rectus femoris muscle. Texture features demonstrate an increased potential towards differentiating neurogenic from myopathic disease.

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CORRELATION ASSESSMENT OF PET/CT RADIOMIC FEATURES WITH GENE EXPRESSION PROFILES IN NON-SMALL CELL LUNG CANCER

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Purpose: To investigate associations between quantitative radiomic features extracted from Positron Emission Tomography (PET)/ Computed Tomography (CT) images and RNA sequencing data from patients with non-small cell lung cancer (NSCLC).
Material and methods: The NSCLC-Radiogenomics dataset from the cancer imaging archive (TCIA) was evaluated for this study. For each segmented tumor in PET/CT scans, 944 radiomics features were extracted. Following unsupervised clustering of both PET radiomic features and CT radiomic features, $\chi 2$ tests were used to evaluate the differences in cluster space against available clinical and transcriptomic data. For each radiomic feature, we calculated its correlation with patient gene expression, using a combination of Spearman rank and associated p-value to assess the level of association of gene expression correlation against each radiomic feature. Finally, each high-ranked group of genes was examined using gene set enrichment analysis (GSEA) to identify gene ontology (GO) terms associated with specific radiomic features.
Results: Comparing the clusters of samples with the available clinical data, we observed that CT clusters had significant correlations with the overall stage (P=0.008, $\chi 2$-test) and primary tumor stage (T-stage; P=0.001, $\chi 2$-test), and PET clusters had significant correlations with the overall stage (P=0.004, $\chi 2$-test), primary tumor stage (T-stage; P=0.014, $\chi 2$-test) and with the lymph node stage (N-stage; P=0.020, $\chi 2$-test). Both CT radiomic features (including firstorder_90Percentile, firstorder_Uniformity, and glszm_GrayLevelNonUniformity) and PET radiomic features (including firstorder-Variance, firstorder-10Percentile, firstorder_ Entropy and glrlm-HighGrayLevelRunEmphasis) were found to have significant correlations (P<0.05 and FDR≤0.20) with specific genes and GO terms (in particular Cell Cycle, Cell division, Mitosis, and DNA replication). Compared to CT features, the PET radiomic features were found to have a greater association with gene expression profiles and GO terms (26/489 CT radiomic features and 43/274 PET radiomic features).
Conclusions: Radiomic features extracted from PET and CT modalities provide valuable tumor characteristics ranging from anatomical features in CT to metabolic properties in PET. On the other hand, an integrative radiomic analysis of PET/CT image biomarkers in NSCLC yielded associations with both gene expression profile and clinical data. The integration of image biomarkers with genomic data has great potential in offering a means of non-invasively characterizing cancer genotypes and can provide a personalized medicine means of improving clinical outcomes.

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A 3D PRINTED PHANTOM STUDY OF THE IMPACT OF RECONSTRUCTION PARAMETERS AND USED RADIOISOTOPES ON PET RADIOMIC FEATURES

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Purpose: to analyze the impact of reconstruction parameters and of the used radioisotope on PET radiomic features evaluated for a phantom with 3D printed simulated lesions.
Material and methods: The spheres of the NEMA NU 2-2012 IQ phantom were replaced by six 3D printed inserts simulating heterogeneous uptake and realistic tumor shapes. The inserts were designed according to Neuro Endocrine Tumors (NET) extracted from patient studies. Simulated lesions consist of a single compartment with a necrotic core, with a maximum size of 54 mm.
The phantom was scanned twice with different radioisotope solutions (18F and 68Ga), using the list-mode in order to allow subsequent reconstructions with different acquisition times. In both cases, the lesions were filled with the same activity solutions of 21 MBq/l and the large background compartment of the NEMA IQ phantom with 5,3 MBq/l. Phantom scans were reconstructed with different parameters (acquisition time: 1.5 - 5 min, iterations: 3-10, subsets: 1 - 35). 52 radiomic features (Rfs), including first order (histogram) and second order (texture), were extracted with LifeX software. Relative trends of RFs and coefficients of variation (COV) were analyzed. Wilkoxon tests were applied to assess the differences between the RF associated with the two isotopes. The RFs' correlation with volume was analyzed by calculating Pearson's correlation coefficients.
Results: Among the acquisition and reconstruction parameters, for both radioisotopes with an equal number of iterations, the number of subsets had the major impact on Rfs, with COV greater than 50% for 13 RF. Relative trends of RFs for different iterations showed in most cases a large variation between 3 and 5 iterations and low changes between 5 and 10 iterations, regardless of the volume of the inserts. For different acquisition times, the majority of RFs showed COV lower than 20%. Significative differences between 18F and 68Ga RFs were observed for 14 RFs (4 conventional and 10 texture RF). Pearson correlation coefficients greater than 0.8 between RFs values and insert volumes were obtained for 75% of RFs for both radioisotopes.
Conclusions: The implemented phantom allows to evaluate the impact of different acquisition and reconstruction parameters on RFs and it can be useful to standardize PET protocols for multicentre radiomics studies.

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DIAGNOSTIC PERFORMANCE OF HUMAN READERS AND ARTIFICIAL INTELLIGENCE MODEL IN CLASSIFICATION TASK OF COMPUTED TOMOGRAPHY IMAGES OF DIFFERENT TYPES OF VIRAL PNEUMONIA

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Purposes: Artificial Intelligence (AI) models are constantly developing to help clinicians in challenging tasks such as classification of images in radiological practice. The aim of this work was to compare the diagnostic performance of an AI classifier model developed in our hospital with the results obtained from the radiologists reading the CT images in discriminating different types of viral pneumonia.

Materials and methods: Chest CT images of 1028 patients with positive swab for SARS-CoV-2 (n=646) and other respiratory viruses (n=382) were segmented automatically for lung extraction and Radiomic Features (RF) of first (n=18) and second (n=120) order were extracted using PyRadiomics tools. RF, together with patient age and sex, were used to develop a Multi-Layer Perceptron classifier to discriminate images of patients with COVID-19 and non-COVID-19 viral pneumonia. The model was trained with 808 CT images performing a LASSO regression (Least Absolute Shrinkage and Selection Operator), a hyper-parameter tuning and a final 4-fold cross validation. The remaining 220 CT images (n=151 COVID-19, n=69 non-COVID-19) were used as independent validation (IV) dataset.
Four readers (three radiologists with >10 years of experience and one radiology resident with 3 years of experience) were recruited to blindly evaluate the IV dataset using the 5-points scale CO-RADS score. CT images with CO-RADS ≥3 were considered "COVID-19". The same images were classified as "COVID-19" or "non-COVID-19" by applying the AI model with a threshold on the predicted values of 0.5. Diagnostic accuracy, specificity, sensibility and F1 score were calculated for human readers and AI model.
Results: The AI model was trained using 24 relevant features while the Area under ROC curve values after 4-fold cross validation and its application to the IV dataset were, respectively, 0.89 and 0.85. Inter-reader agreement in assigning CO-RADS class, analyzed with Fleiss' kappa with ordinal weighting, was good (k=0.68; IC95% 0.63-0.72) and diagnostic performance were then averaged among readers. Diagnostic accuracy, specificity, sensibility and F1 score resulted 78.6%, 78.3%, 78.8% and 78.5% for AI model and 77.7%, 65.6%, 83.3% and 72.0% for human readers. The difference between specificity and sensitivity observed in human readers could be related to the higher rate of false positive due to the higher incidence of COVID-19 patients in comparison with other types of viral pneumonitis during the last 2 years.
Conclusions: A model based on RF and artificial intelligence provides comparable results with human readers in terms of diagnostic performance in a classification task.

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PROSTATE CANCER RISK CLASSIFICATION FROM MULTIPARAMETRIC MRI AND PET IMAGE DATA EVALUATED BY REGISTERED HISTOPATHOLOGY

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Purpose: Prostate cancer (PCa) patients would greatly benefit from non-invasive methods to predict the degree of malignancy. The reference standard to assess malignancy is histopathologic grading, where ISUP Grade Groups, comprised out of Gleason Scores (GS), play a central role. The purpose of this work was to discriminate between ISUP grade 2 (GS 3+4) and ISUP grade 3 (GS 4+3) by using ^{68}Ga-PSMA-11-positron-emission tomography (PET)/multiparametric magnetic resonance imaging (mpMRI) and ^{11}C-acetate PET/CT.
Material and methods: 55 consecutive patients with biopsy-verified intermediate and high-risk PCa planned for radical prostatectomy were examined with PET/mpMRI and PET/CT. The mpMRI included T2-weighted (T2w), diffusion-weighted (DWI) and dynamic contrast-enhanced MRI sequences. Prostates were contoured on the T2w image, and a 3-D printed mold was tailored for each patient to fit their prostate. Following surgery, a prostate was placed inside its mold and scanned to yield ex-vivo T2w images of the prostate, whereafter it was sectioned in alignment with the ex-vivo slices and annotated by a pathologist, resulting in regions of interest showing the location of lesions and their ISUP grade. As such, the examined lesions are not dependent on MR or PET based detection.
All images were aligned with the corresponding patient's in-vivo T2w image and three image features were determined per lesion: the maximum standard uptake value (SUVmax) for ^{68}Ga-PSMA and ^{11}C-acetate, and apparent diffusion coefficient (ADC). The ADC maps were calculated from the DWI and the median ADC per lesion was normalized to the mean ADC of healthy tissue, defined as the part of the peripheral zone not containing lesions. The set of all unique combinations of these three imaging features were used as thresholds to classify lesions, and the performance of classifications were evaluated by ROC analysis. The results are based on a subset consisting of 93 lesions (ISUP grade 2, n=57 vs ISUP grade 3, n=36) all having an in-plane area greater than 20 mm^2.
Results: The area under the ROC curve (AUC) was 0.85, where the optimal thresholds given by the highest Youden index resulted in a specificity and sensitivity of 84% and 69%, respectively. Only using the SUVmax threshold for ^{68}Ga-PSMA we obtain equal specificity (84%) and moderately lower sensitivity (58%).
Conclusion: ^{68}Ga-PSMA/^{11}C-acetate PET and mpMRI appears to differentiate between ISUP grade 2 and ISUP grade 3, and in combination the predictive power increases.

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SEGMENTATION OF THE PROSTATE AND ANATOMICAL ZONES IN T2W MRI IMAGES USING A 3D U-NET

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Purpose: Segmentation of the prostate and its anatomical zones in MRI is an important step in many diagnostic applications. This task can be time-consuming, and is a good candidate for automation using a neural network. The aim of this work was to train a convolutional neural network (CNN) that segments the prostate and its four anatomical zones for use as decision support in the delineation process. The segmentations should be represented as DICOM RTSTRUCTs, and the whole solution should be easily integrated into the DICOM workflow without the need to export and import anonymous data into the clinical systems.
Material and methods: Our architecture is a 3D U-NET. Ninety-eight T2w MRI series from the publicly available SPIE-AAPM-NCI PROSTATEx challenge dataset [1] were used for training (n=78) and validation (n=20). Forty T2w MRI series from patients with intermediate and high-risk prostate cancer examined at Umeå University Hospital, were used for testing (IRB: 2016- 229-31M). Prior to training, the delineations of the anterior fibromuscular stroma (AFS), peripheral (PZ), central (CZ) and transitional (TZ) zones, and an additional anatomical landmark, the Urethra (U), were validated in collaboration with an experienced radiologist.

The model was trained using the combined Dice scores [2] from all the zones as a loss function. Preprocessing, postprocessing and the model evaluations were performed in MICE Toolkit [3].

Results: The Dice score average±standard deviation for the segmentation of the prostate was 0.88±0.05, and the Dice scores of the internal zones were: PZ:0.72±0.07, CZ: 0.40±0.16, TZ: 0.72±0.16, U: 0.05±0.03, AFS: 0.34±0.15, for the test dataset. Accurate segmentation of the Urethra was challenging due the small diameter of the structure, and can easily be discarded when reviewing the structures. The CNN can be used in MICE Toolkit, which has support for sending and receiving DICOM images and RTSTRUCTs. This simplifies the integration with any software that uses the DICOM protocol.

Conclusions: The trained CNN is available online[4], and can be used as decision support for prostate zone delineation, and can be integrated into any workflow using the DICOM protocol.

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POSTER ABSTRACTS – BIOMEDICAL ENGINEERING

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THREE-DIMENSIONAL ULTRASOUND SYSTEM PERFORMANCE IN UROLOGY

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Ultrasound imaging provides an important non-invasive modality for measuring anatomical and pathological structures. The role of quantitative measurements in urology ultrasound imaging has progressed with advances in ultrasound technology being relied upon for making measurements of structures of urological interest. An important part of the patient imaging with 3D ultrasound is to provide image data of sufficient quality to measure the length, area or volume of organs and to follow their temporal changes. While qualitative visual assessment is valuable, quantitative data provides a more accurate basis for decision making.

In urological applications measuring organ volume, rather than its diameter or perimeter, is the goal. However, conventional ultrasound imaging provides 2D images, from which 3D structure must be estimated. In this study is analyzed accuracy and reproducibility of estimating techniques for estimate prostate dimensions.

Because ultrasound images are tomographic in nature, measurement of length within the 2D images are always been possible. The accuracy and precision of the measurement depends on the frequency of the transducer, field-of-wiew, and the resolution of the ultrasound machine. The separation between wire layers were then measured in 3D images of prostates in 150 patients. The results of this study showed that, with proper calibration of the scanning geometry a 3D ultrasound imaging system can provide distance measurement with an error about 1.1%.

An important application of 3D ultrasound imaging is the measurement of prostate volume for normalizing the PSA value. The study shows also a least-squares regression measured versus true volume resulted in a best-fit line with a slope of 1.0005±0.0040 and a correlation coefficient of 0.99996.

To examine the effect of the choice of interstice distance repeated measures were performed on the same prostate. The result showed that the measured prostate volume was constant up to interstice of 8mm. An interstice distances greater than 8mm resulted in an underestimation of the prostate volume. For prostate volume measurement is used an ellipsoid of V= (π/6)HWL where H is the height, W is the width, and L is the length L of the prostate. Because the prostate is not ellipsoidal, choosing the appropriate orthogonal wiews is largely dependent on observer performance. However, with 3D ultrasound, the entire prostate is available for volume measurement. Thus, any arbitrarily shaped volume can be measured and the only observer variability is in deciding the boundary of the anatomical structure.

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DAILY DOSE EVALUATION BASED ON SYNTHETIC CTS FOR BREAST CANCER PATIENTS: ACCURACY OF DOSE AND COMPLICATION RISK ASSESSMENT

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Objectives: The goal of this study was to assess breast volume changes by investigating dose deviations and their influence on complication risk assessment in breast cancer patients undergoing photon radiotherapy employing CBCT based synthetic CTs generated with four different methods.

Materials and methods: Seventy-six breast cancer patients treated with a partial VMAT photon technique were included. Forty-three patients received a fractionation of 21x2.17Gy(+0.49Gy) while the other thirty-three received 16x2.66Gy. All patients showed >5mm swelling or shrinkage of the breast on the CBCT compared to the planning-CT (pCT), followed by a repeat-CT (rCT) for dose evaluation. The original CBCT was corrected using four different methods: 1) HU-override correction (CBCT-HU), 2) analytical correction and conversion (CBCT-CC), 3) deep learning correction (CT-DL) and 4) virtual (CT-V). Thirty-seven patients were used for deep learning model training and validation. Thirty-nine patients have been used for image quality evaluation and dose calculation using the rCT as reference. Image quality evaluation consisted of calculating the mean absolute error (MAE) and mean error (ME) within the clinical target volume (CTV) and the field of view of the CBCT minus 2 cm (CBCT-ROI). The dose was calculated on all image sets using the pCT beamset to determine voxel-based dose parameters of the CTVs and heart. The mean heart dose (MHD) was used in combination with the normal tissue complication probability model for acute coronary events (ACE) to assess clinical impact of the dose variations between the different synthetic CTs.

Results: The image quality evaluation showed larger HU deviations for the CBCT-ROI than for the whole breast CTV, due to the inclusion of more heterogeneous tissues. The dose difference as percentage of the prescribed dose between the rCT and pCT for the whole breast CTV is on average 0.4% (±0.8%) which is considered to be due to anatomical changes. The CBCT-HU deviates significantly ($p<0.01$) from the rCT over all dose statistics, resulting in 1.7%(±1.1%) average dose deviation. The CBCT-CC shows minimal deviations with 0.0%(±1.0%) as average dose deviation. The MHD varies at max 6 cGy, which corresponds to a max change in risk of an ACE by 0.05%.

Conclusion: The analytical correction and conversion, deep learning correction and virtual CT can be applied for an accurate synthetic CBCT dose evaluation for photon radiotherapy breast cancer patients as there is no statistical difference relative to the reference. The complication risk assessment considering ACE is negligible amongst the different synthetic CTs.

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NON-INVASIVE APPROACH FOR ASSESSING NEUROCARDIOVASCULAR FUNCTION IN PATIENTS AT RISK OF FALLS AND SYNCOPE

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Purpose: Studies report that 30% to 60% of people aged 65 years and older fall at least once per year, with 25% of unexplained falls (UF). Current hypotheses suggest cerebral hypoperfusion as an attributable cause in many UFs. Despite cerebral autoregulation (CAR) being a key brain blood flow regulation system, little is known about its role in UF. Correctly assessing cerebral perfusion and its autoregulation, while paramount in clinical assessment, requires the development and validation of a suitable protocol for use in often frailer patient cohorts. This research aims to develop a protocol suitable for use in a clinical setting to detect impaired CAR.
Material and methods: The protocol uses non-invasive near-infrared spectroscopy (PortaLite®, Artinis Medical Systems, Einsteinweg, The Netherlands) and a Finometer (NOVA, Finapres Medical Systems, Amsterdam, The Netherlands) to measure continuous tissue saturation (TSI) and blood pressure (BP) respectively. Following 5 minutes supine rest, orthostatic BP responses were elicited by a 3 minute active stand and repeated sit-to-stands. The recorded signals were analysed to derive CAR indices using Transfer Function Analysis (TFA) based on recommendations from the Cerebral Autoregulation Research Network. This protocol was tested on n=1 (young and healthy participant) as a pilot for a larger clinical study.
Results: Active stands induce a BP drop of approximately 20mmHg, however the cerebral tissue oxygenation remained relatively constant (drop <1%) and BP recovered to baseline within 20 seconds. The repeated sit-to-stands induced a smaller drop in BP of approximately 10mmHg, with fluctuations occurring at 0.1Hz. As more sit-to-stands are performed, the mean blood pressure rises. Similarly to the active stand, minimal drops in cerebral oxygenation were noted, with TFA feasible on this data.
Conclusions: CAR assessments protocols are practical, being feasible for clinical implementation with modification. Despite significant BP drops, only small transient cerebral oxygenation fluctuations were observed, with BP responses recovering quickly following standing with similar responses noted with sit-to-stand protocols and TFA. This process with further validation may provide relevant insights on neurocardiovascular function and will be further investigated on a larger clinical group.

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COVID-19 TECHNOLOGY ASSESSMENT SERVICE

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Purpose: As the COVID-19 emergency evolved, a wide range of 'new' technology based solutions were offered to meet clinical and occupational health needs in Europe. This technology extended beyond the standard medical devices usually deployed in clinical settings, and therefore required rapid assessment of suitability for use in hospitals. Here we describe a hospital-based COVID-19 technology assessment service (www.misa.ie/research-development/bioengineering-lab/technology-assessment) that was developed and share our experience of its implementation.
Materials and methods: A scientifically grounded assessment service was established to evaluate specific technological solutions. This service was led by a team of 2 Senior Medical Physicists and 1 Senior Clinical Engineer, with each assessment drawing on pan-hospital expertise and a specialist technology evaluation infrastructure. Each solution was evaluated using a standardized agile process: 1) user centric needs assessment; 2) applicable literature and international standards review; 3) balanced risk-benefit assessment; 4) initial device functionality and usability assessment; 5) in-depth device technical testing and safety assessment; 6) rapid communications and detailed reporting; 7) support for local clinical implementation/installation with on-going evaluation. Evaluations were described in the form of short Bulletins with a webpage developed to share these findings internationally.
Results: To date, a diverse range of technological systems and innovative solutions were evaluated, including thermal cameras for mass temperature screening, baby monitor devices for isolation room communications, augmented reality systems, a varied range of thermometers, and connected health technologies for remote working and clinical testing. Substantial variability in quality and standard of systems on offer was identified, with potential patient risks highlighted and mitigated. Critical success factors of the assessment service identified include: a central focus on the impact of solutions on both patients and staff, accessible local scientific and technical expertise supporting real-world testing and user feedback, an agile process which was responsive to high levels of uncertainty and a rapid communications process that was adaptive, responsive and connected both locally and nationally.
Conclusion: Emergency situations, while challenging, are a huge stimulus for healthcare system-wide changes where barriers to technological innovation are significantly reduced, providing significant opportunities for adoption of new and innovative solutions. While there is a need for timely and practical technology assessments during an acute emergency, these should still be grounded in well-established scientific and safety principles that prioritize the health and safety of patients, staff and the public. A hospital-based COVID-19 technology assessment service has provided a practical and successful solution to this challenge.

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AUTOMATED CLOSED LOOP CONTROL OF NORADRENALINE DELIVERY TO ICU PATIENTS

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Purpose: Management of blood pressure (BP) in patients admitted to ICU is a major clinical challenge, with noradrenaline administration paramount. The importance of minimizing time spent in hypotension is well documented, with mortality rates twice as high for septic patients with hypotension. The clinical complexity of ICU patients, combined with the challenge of second-by-second monitoring of mean arterial pressure (MAP), increases the risk of MAP frequently falling outside of the target range.
Automated closed-loop noradrenaline delivery-based control systems offer a potential solution to this challenge – however, no systems are currently available to support this function, especially during vasopressor weaning. Here we describe the initial design,

development, and verification of a prototype system designed to address this need.
Material and methods: The initial clinical need and requirements were defined through a process of expert interviews with clinical personnel, a state-of-the-art literature review, and observation and workflow mapping of current BP management processes in the ICU. An iterative, rapid prototyping design process was adopted to create a solution designed to meet clinical requirements. The initial prototype module was a MAP-driven automated syringe driver system. It consisted of an Arduino-Uno-Rev3 based control system, programmed to provide accurate flowrate control of a 10ml syringe, using a PWM-driven DC motor. Following this, the system was modified to incorporate MAP-driven control of flowrate, with continuous BP measured in real-time using a Finometer Pro and digitized using the Arduino ADC (9600Hz). Verification of the prototype was performed by testing each subset of the system (MAP readings, calculated and achieved flowrates, flowrate response to BP changes).
Results: Initial clinical needs and design requirements were defined for the system. The initial prototype system was able to achieve flowrates (1ml/hr–60ml/hr) with an average accuracy of 97.06%. When connected to the Finometer, the prototype responds autonomously to vary its flowrate according to the MAP and matches the nature of the current clinical processes. The flowrate increases (when MAP<65mmHg) and decreases (when MAP<80mmHg) in user-definable increments (0.1–5ml/hr). Target levels and incremental noradrenaline dose changes are adjustable by the end user.
Conclusions: An automated closed-loop noradrenaline delivery system for ICU patients offers potential to aid current BP management processes within ICU. A successful logic-based prototype was designed, developed, and verified to automate current clinical processes. Future work will focus on further prototype refinements, closed-loop control system design and development of an in-silico simulated patient to verify the closed-loop performance of the prototype.

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PULSE ARRIVAL TIME AS A SURROGATE OF CONTINUOUS BLOOD PRESSURE IN PATIENTS WITH SYNCOPE

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Purpose: Syncope and unexplained falls are common conditions affecting older adults. They can happen infrequently and without forewarning symptoms with prolonged monitoring of cardiovascular parameters often required for their diagnosis. State-of-the-art blood pressure (BP) measurement systems are not suitable for convenient continuous ambulatory monitoring. The aim of this study was to explore the correlations between pulse arrival time (PAT) and BP during different epochs of an active stand (AS) in order to assess the feasibility of using it in a model for estimating continuous ambulatory BP.
Material and methods: Patients from a Falls and Syncope Unit were recruited together with a group of healthy volunteers. Participants lay supine for a 5-minute resting period followed by a 3-minute AS with continuous beat-to-beat BP and ECG recorded with Finapres® NOVA (Finapres Medical Systems, Amsterdam). PAT was estimated as the time between the ECG R wave and the finger diastolic BP times. The data was filtered, key features were extracted and signals were epoched into resting (5 min pre AS) and the initial BP stabilisation (first 60s after the AS) periods using MATLAB_R2020a®. Correlations (mean correlation +/- SD) between inverse PAT2 and absolute BP during the supine resting period and between changes in inverse PAT2 and changes in BP (from baseline) during initial stabilisation were obtained for each individual using RStudio v.13959.
Results: Data from 20 patients (73.6+/-8.3 years, 40% female) and 20 healthy participants (30.85+/-9.9 years, 35% female) was obtained. BP versus inverse PAT2 correlations during rest were rSBP=0.24+/-0.16 ($p<0.001$), rDBP=0.12+/-0.16($p<0.001$) and rMAP=0.18+/-0.15 ($p<0.001$), while during the initial transient stabilisation period they were rSBP=0.32+/-0.31 ($p<0.001$), rDBP= 0.15+/-0.32 ($p<0.001$) and rMAP=0.26+/-0.31 ($p<0.001$).
Conclusions: These results demonstrate a higher correlation between inverse PAT2 and systolic blood pressure, with highest correlations noted during initial BP stabilisation. However, with low overall correlations during both resting (absolute values) and transient periods (dynamic values) these findings would suggest that simple PAT-based measures alone are poor surrogates of continuous beat-to-beat BP values.

POSTER ABSTRACTS – DIR

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RADIATION DOSE REDUCTION OF SPECTRAL SHAPING CT IN CT-GUIDED INTERVENTIONAL PROCEDURES BY TIN PRE-FILTRATION

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Purpose: Besides beam hardening and beam shaping pre-filtration, additional spectral shaping pre-filtration was implemented in some of the computed tomography (CT) scanners nowadays. The aim of this study was to investigate the amount of patient radiation dose reduction in terms of peak skin dose and effective dose using spectral shaping CT by tin pre-filtration in a typical CT-guided interventional procedure.
Material and methods: A total of 33 CT-guided percutaneous lung fine-needle aspiration biopsies (FNAB) performed in adult patients were retrospectively studied. Among them, one-third were scanned with additional tin filter in Siemens Somaton Definition Edge. The remaining two-thirds were scanned without additional spectral shaping filter in Siemens Somaton Definition Flash (50%) and in Philips Ingenuity 64 (50%). The radiation dose output of the three scanners performed with protocols in our center was compared. Peak skin dose was estimated from volumetric CT dose index (CTDIvol). Effective dose was calculated using ImPACT CTDosimetry spreadsheet version 1.0.4 with NRPB SR250 Monte Carlo normalized organ dose data.
Results: During the step of needle placement, insertion and incremental advancement, Definition Edge showed 73% and 82% reduction in CTDIvol compared with Definition Flash and Ingenuity, respectively. The mean peak skin dose scanned in each of the three scanners were 3.38±3.9 mGy, 6.70±4.3 mGy and 10.59±5 mGy, respectively. The corresponding mean effective dose were 0.41±0.4 mSv, 0.68±0.9 mSv and 1.46±0.9 mSv.
Conclusions: The step of needle positioning and insertion towards the target could be a large contributor to patient radiation dose due to the repeated scan of the same anatomic region. Tin pre-filtration could significantly reduce that as observed from the protocols used in our center. Although patient radiation dose depends on the complexity of the procedure and radiologists' experience, the results obtained in our center could serve as a reference. The mean peak skin dose was far below the threshold for deterministic effects, while average stochastic risk was comparable to that of a two-view 2D digital mammogram.

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QUANTITATIVE AND QUALITATIVE COMPARISON OF DIFFERENT TYPES OF DIFFUSION-WEIGHTED IMAGING (DWI) SEQUENCES: A PHANTOM STUDY

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Purpose: Diffusion Weighed Imaging is an important form of MR imagining for diagnosis. It has a major role in many clinical situations including early identification of ischemic stroke, differentiation between cholesteatoma and otitis media, grading of prostate lesions and so on. The most commonly used single shot echo-planar sequence DWI (SS EPI DWI) is vulnerable to artifacts, geometry distortion and signal loss especially in the region where tissues are adjacent or within bone and air. In order to overcome the drawback of the conventional SS EPI DWI, a variety of DWI sequences have been developed to generate diffusion maps. The purpose of this study was to quantitatively and qualitatively compare the image quality and mapping accuracy among different DWI techniques.
Material and methods: The home made phantom consisted of a plastic tube filled with distilled water immerged in the ice-water. The phantom in thermal equilibrium was investigated with four different DWI sequences. All DWI data was collected at 1.5T MR system (Achieva, Philips Healthcare)) with an 8-channel head coil. The image sequence included routine SS EPI DWI, multi shot EPI DWI (MS EPI DWI), Single shot non-EPI DWI (SS TSE DWI) and multi shot non-EPI DWI (MS TSE DWI). All sequences were acquired with 2 b values (0, 1000s/mm2) respectively. Image quality of the different sequences was quatitatively assessed in regard to the overall image quality and measurement accuracy. Region of interest (ROI) was placed on the center of the distilled water tube to quantify the apparent diffusion coefficient (ADC), Signal-to-noise ratio (SNR) and geometric distortion.
Results: Based on the published paper, the ADC value of 1.1×10^(-3) mm^2/s measured at 0^0 C by M. Holz and co-workers (Phys ChemChem Phys 2000;2:4740–4742) used as reference for accuracy evaluation. The PE=7.1%, 1.2%, 2.2% and 3.1%,the SNR is 4.7, 1.4, 1.3, 2.0 after normalization, the geometric distortion ratio for perimeter is 128.4%, 98.8%, 99.3%, 99.7% for for SS EPI, MS EPI, MS TSE and SS TSE DWI respectively.
Conclusions: Based on the phantom study, all protocols provide precise ADC measurement with PE<8% and MS EPI DWI presents the best measurement. The SNR of SS EPI DWI is the highest after normalization. The distortion of SS EPI DWI is the severest. Due to the severe distortion, the delineation of anatomical structures and lesion was affected for the protocol SS EPI DWI even it owns the highest normalized SNR.

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DOSE REDUCTION IN MULTIPHASE CONTRAST ENHANCED THORAX-ABDOMEN CLINICAL CT PROTOCOL USING NOVEL TRUE FIDELITY RECONSTRUCTION ALGORITHM

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Purpose: Aim of the study was to optimize the thorax-abdomen clinical protocol reducing the dose to the patients and maintaining an optimal image quality.
Material and methods: From January 2021 to September 2021 a total of 692 patients underwent a multiphase contrast enhanced thorax-abdomen CT using a Revolution Evo CT system (GE Healthcare). The CT exams were initially acquired with the following parameters: 120 kV, pitch 0.52, 0.4s, 40mm, 2.5mm and Noise Index (NI) 22 for all phases (mA range 80-450 for basal and 120-450 for other phases with contrast medium).
To reconstruct the clinical images with 1.25 mm thickness we used both ASIR (AR60) and True Fidelity with "medium" strength.
After progressive reduction of NI and mA range (60-350), subsequent to image quality evaluation from experienced radiologists, the final "low dose" clinical protocol used NI 28 for basal phase and 27 for arterial, venous and late venous phase, with a reconstruction of 1.25 mm thickness using True Fidelity with "high" strength.
Median values for CTDIvol (mGy) and DLP (Dose Lenght Product, mGy•cm) were registered and compared.
Results: For basal phase the median results in terms of CTDIvol and DLP for initial protocol were respectively 7.1mGy and 349.7mGy•cm while for "low dose" protocol the results were 4.5mGy and 228.0mGy•cm.
For arterial and late venous phase CTDIvol and DLP were initially 8.5mGy and 393.4mGy•cm and for "low dose" 5.5mGy and 268.7mGy•cm.
For all phases the average reduction in terms of CTDIvol and DLP was respectively -36% and -33%.
Conclusions: The use of the novel True Fidelity reconstruction algorithm increase significantly the image quality, allowing to significantly reduce the dose both in terms of CTDIvol and DLP, and thus the absorbed dose to the patients.

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PATIENT DOSE IN PROSTATIC ARTERY EMBOLIZATION: STATE OF ART AT MORGAGNI PIERANTONI HOSPITAL

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Purpose: The aim of this work is to evaluate the radiation dose in patients undergoing prostatic artery embolization (PAE) in the Diagnostic Imaging Department of the Morgagni Pierantoni Hospital.
As PAE is a newly performed procedure in this hospital, monitoring the dosimetric state of art of this interventional tecnique is of particular relevance to implement subsequent optimizations, if necessary.
Materials and methods: In this retrospective study, all the patients (16) treated using PAE between January and August 2021 were considered. All patients received at least 1 intraprocedural conebeam CT and DSA was performed. The total dose area product (DAP), along with the DAP attributed to fluoroscopy, and cone-beam CT, were assessed. Values for fluoroscopy time (in minutes), dose area product (DAP) (in Gy × cm2), number of DSA series, and cone-beam CTs were extracted from the automated dose report stored in the picture archiving and communication system. DAP totals for fluoroscopy, DSA, and cone-beam CT were analyzed separately. Fluoroscopy was performed at 12fps, and with no zoom. For cone-beam CT, 480 projections were acquired during a 180° rotation scan (8-second acquisition time; 60 frames per second; field of view, 25×25×19 cm; matrix size, 384×384×296; and isotropic resolution, 0.6 mm).
A comparison with previously published data was also effected.
Results: The total DAP was 391.9 Gycm2±228 (mean±sdev, range 149–926 Gycm2). Fluoroscopy accounted for 192.6 Gycm2±138 (range 56.9–523 Gycm2) or 49.6% (percentage of total DAP).Mean

number of CBCT series per procedure is 3.62 (range 2-7) and median DAP is 46.5 Gycm2±19 (range, 23.8–98 Gycm2) or 11.86% of total DAP. Air Kerma at the interventional reference point was 1449.1±738 mGy, and the fluoroscopy time was 55 ±16 minutes.
Conclusions: PAE must be considered a high-dose procedure. Average Total DAP value results higher than the one published by Shott et al. (J. Vasc. Interv. Radiol. 2019) and also mean fluoroscopy time which are 134.4 Gycm2 and 30.9 min respectively.
Also percentage of fluoroscopy DAP above total DAP results higher than the published one (26%).
Average Cone Beam CT contribution is comparable to published result (40.7 Gycm2).

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IMPLEMENTATION AND VALIDATION OF IAEA REMOTE X-RAY QC GUIDANCE

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Purpose: The recent release of routine QC software and phantom guidance from the IAEA has prompted a review of current medical physics quantitative methods. The IAEA software offers a valuable addition to the medical physicist's toolbox. The release of official blueprints may allow increased standardisation and cross comparison between departments, providing an opportunity for remote QC at sites external to the Radiology department. Our project reviews the local implementation and validation of these tools.
Material and methods: The IAEA has provided radiology phantom blueprints and freely available software download on its website. These resources were compared to our current methods of image quality assessment and cross calibration factors generated. These cross calibration factors allow for comparison against medical physics annual QA baseline results. The phantom was tested in multiple orientations and for various exposure parameters to assess the likely variation expected for normal use. The software was compared directly to currently used software packages such as COQ and DRIQ. Some metrics were not directly comparable. These are detailed in results.
Results: The IAEA guidance for parameter assessment and the current local protocols were compared. Variation between methods are attributed to differing exposure parameters. All exposure parameters were recorded and differences noted. IAEA guidance also gave typical corrective actions for issues which may occur in routine testing.
Conclusions: The IAEA remote QC guidance is a useful, practical and fiscally responsible method to routinely assess radiology equipment. By performing robust commissioning measurements, it is possible to directly compare traditional physics testing results with the new techniques and phantoms proposed.

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PATIENT EXPOSURE DURING LOWER EXTREMITY ENDOVASCULAR AND HYBRID PROCEDURES – A MULTICENTER STUDY

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Purpose: The number of performed fluoroscopy-guided peripheral endovascular procedures has significantly increased the last decades. Complex, prolonged and repeated procedures can result in significantly high radiation doses.
The purpose of the study was to survey patient exposure during lower extremity endovascular and hybrid procedures in several departments in Bulgaria.
Material and methods: This is a retrospective study. Data for 220 complex procedures, performed in 3 hybrid operating theatres (111) and 4 catheterization suites (109), was analysed, including patient's age, height, weight, gender, exposure parameters, fluoroscopy time (FT), displayed air kerma-area product (KAP) values, cumulative dose at the interventional reference point (IRP), number of series and images, type and complexity of procedures.
For the purpose of the study, descriptive, variation and non-parametric analysis (K Independent Samples/Median test /) were used. Statistical processing was performed with SPSS.
Results: The mean age was 68 years (range 34-90, 9.3 standard deviation), 72.4% were men. A significant variation in the median KAP values among the different suites was observed, up to factor of 2.5 for procedures with the same degree of complexity performed in the endovascular suits and up to factor of 12 for those performed in angiography rooms. The median KAP values for each catheterization room were the following: 7112 cGy.cm^2 (II); 4835 cGy.cm^2 (IIIB); 23779 cGy.cm^2 (IIIC); and 1986 cGy.cm^2 (V). The median KAP values for each hybrid suit were: 1520 cGy.cm^2 (I); 3095 cGy.cm^2 (IIIA) and 1260 cGy.cm^2 (IV). Patient KAP exceeded the SAFRAD trigger level of 50 000 cGy.cm^2 in 2% of all procedures, a threshold above which follow-up procedure for radiation-induced skin effects is indicated. The patients reported no such effects.
Conclusions: An extended multicenter study for patient exposure during lower extremity endovascular and hybrid procedures was performed for first time in Bulgaria. The results showed that patient exposure during procedures of the same degree of complexity performed in the catheterization rooms is significantly higher than those performed in the hybrid operating theatres ($p < 0.05$).

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STRATEGIC PLANNING IN MEDICAL PHYSICS: A SWOT ANALYSIS OF A DIAGNOSTIC RADIOLOGY CONSTANCY TESTING PROGRAMME FOR MEDICAL IMAGING DEVICES IN A MAJOR HOSPITAL IN MALTA

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Purpose: Medical Physics is a young profession in Malta. The present constancy testing programme at the hospital concerned is younger still. It was therefore felt necessary that a strategic evaluation of the current state of the programme be carried out. The purpose of the study was therefore first to develop an updated vision statement for the present constancy testing programme which complies with international standards for constancy testing programmes and with the role of the hospital within Maltese society and healthcare system. This was then followed by a SWOT thematic analysis to evaluate the current programme. Finally, recommendations for improvement in terms of a list of strategic objectives for the programme were drawn up.

Material and methods: Using a qualitative research approach, data were collected by means of semi-structured interviews with the Medical Physics professionals involved in the programme, on-site observations, and the analysis of associated documentation. The interviews were audio-recorded, transcribed, and analysed using NVivo software. SWOT themes were derived from the qualitative data using thematic analysis.
Results: A vision statement for the programme was developed. Internal strengths and weaknesses of the present constancy testing programme at the hospital concerned along with external opportunities and threats were identified. A degree of relevance metric was assigned to each SWOT theme. A set of strategic objectives was developed by matching strengths and weaknesses with opportunities and threats.
Conclusions: The current programme has several strengths but also several weaknesses, mainly derived from the profession being so young in Malta. Fortunately, several opportunities for programme improvement are available, however, some threats do exist. By keeping patient service in mind and taking strategic management approaches, a bright future for the constancy testing programme can be assured.
(All statements made regarding the operations at the hospital concerned or the findings of the study reflect the opinions of those interviewed.)

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VALIDATION OF AN AUTOMATIC EFFECTIVE DOSE CALCULATION SYSTEM FOR TC EXAMS COMBINED WITH A RDIM SYSTEM

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Purpose: Aim of the study is to evaluate the performances of Virtual Dose CT (Virtual Phantom inc.) (VD), a monte-carlo based effective dose calculator, used in combination with Gray Detector (ELCO srl.), an RDIM system, to estimate effective dose to patient in TC procedures.
Materials and methods: Seven CT scanner of different manufacturers (Siemens, GE, Philips) installed in our institution are connected to Gray Detector that collects expositions data form RDSR. These data are automatically sent to VD for patient effective dose calculation.
First, ten examinations for each scanner were manually simulated with VD and CT-Expo varying on both system exposure parameters (mAs, kV, pitch and collimation) in order to establish the different impact of those parameters on effective dose calculation.
Then the results obtained with the automatic procedure of effective dose calculation were compared with those obtained with the manual one for 194 exams performed by different scanners with different scan protocols, to highlight possible data transmission or interpretation error arising from the entire automatic calculation chain.
Results: Varying mAs and pitch values patient effective dose calculated by VD is about 10% lower than CT-Expo dose. Moving kV values from 80 kV to 140kV, the differences in dose values calculate by VD with respect to CT-Expo move from -2.2% to +27.4%. By varying the beam collimation, the differences in the effective dose of VD compared with CT-Expo went from +14.1% for 1.25 mm to -9.3% for values greater than 20 mm.
As the automatic procedure of effective dose calculation regards, the results show a mean difference in VD effective dose of about +2.1±3.6 mSv with respect to CT-Expo and -0.6±3.3 mSv with respect to the manual procedure.
Conclusions: Virtual dose represents a simple and effective tool for patient effective dose calculation in CT procedures. The possibility to implement an automatic dose calculation procedure allows to enter the information relating to patient exposure in the report of the medical radiological procedure, as suggested by the 2013/59/Euratom Directive.

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IMPORTANCE OF PHANTOM SIZE IN ASSESSING EFFECTIVE DOSE FROM CT EXAMS

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Purpose: To evaluate the influence of the phantom-size in patient effective dose estimations performed by VirtualDose (Virtual Phantom Inc.) (VD) in combination with an RDIM software in CT procedures.
Materials and methods: 56 CT exams (head, thorax, abdomen-pelvis and thorax-abdomen) were simulated for seven different scanners (Siemens, General Electric, Philips) using the different male and female adult body-size phantoms embedded in the VirtualDose software.
Patient effective dose was calculated using over-weight, obese Lv. I, Obese Lv. II and Morbidly obese phantoms and compared with the effective dose to the normal-weighted phantom.
Results: Results do not show differences between CT models. For the Head protocols the average differences between the effective dose calculated with the 4 over-weighted phantoms and the normal-weight phantom are constant (-0.1%). The effective dose evaluated with the thorax protocol decreases as the phantom dimension increases (from about -7% to -37%). Greater differences were found with the thorax-abdomen and abdomen-pelvis protocol (from about -12% to -55%).
Conclusions: The use of VD without a correct choice of the phantom can lead to an overestimation of the dose up to about 55% and therefore it is a factor to be taken into consideration. For a correct effective dose evaluation, the insertion of weight and height data in the CT unit should become mandatory when creating the patient.

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OBJECTIVE METRIC FOR ASSESSMENT OF LANGUAGE LATERALIZATION IN HEALTHY SUBJECTS AND EPILEPTIC PATIENTS

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Purpose: To develop a pipeline for fMRI data processing and for Laterality Index (LI) calculation, an objective metric that provides practical clinical support for the assessment of language lateralization.
Material and methods: The pipeline was developed within Nipype environment (Neuroimaging in Python: Pipelines and Interfaces https://nipype.readthedocs.io), an open-source software that enables to interface with neuroimaging software's tools. Specifically, FSL's tools were used to analyze fMRI data (https://fsl.fmrib.ox.ac.

uk/fsl/fslwiki). One method was considered for calculating the Laterality index, i.e. LIAVE, using the following standard formula:

$$LI = (QLH-QRH)/(QLH+QRH) \quad (1)$$

where QLH and QRH represent the average fMRI contrast related to the activity of voxel during an activation-rest task in the left and right brain regions of interest (ROIs) respectively. The method was applied to two cohorts of 93 patients affected by drug-resistant epilepsy and 27 healthy subjects undergoing language fMRI examinations with association, understanding, fluency tasks. The areas of activation related to each functional task were reported by 2 experienced neuroradiologists. Then, subjects and patients were classified as dominant or co-dominant according to the clinical reports reviewed by the neuroradiologists. Using the standard classification of dominance/co-dominance, i.e co-dominance if $|LI| \leq 0.2$, dominance if $|LI| > 0.2$, the agreement of clinical reports with the classification of language lateralization resulting from LIAVE has been evaluated.

Results: The agreement of clinical reports with the classification of language lateralization is 100% for healthy subjects and ranges from 86.0% to 94.6% for patients for the three tasks. In a limited number of patients, LI values disagreed with clinical reports: even if patients were classified by clinical reports as co-dominant LI values resulted higher than 0.2, i.e. resulted classified as dominant by LI metric. Since the accuracy of classification is lower than 100% for patients, the accuracy of classification was studied by varying LI threshold values. LI threshold values of 0.3 and 0.25 led to a better agreement with clinical reports for association and fluency tasks (up to 95.7%), but 100% of agreement can't be obtained.

Conclusions: An objective metric can effectively assess language lateralization in fMRI. LIAVE values correctly describe language lateralization for healthy subjects and provides a practical tool for the neuroradiologists and neurosurgery in the interpretation of clinical data and in the classification of most of the patients affected by drug-resistant epilepsy.

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OPEN DATA FOR CBCT RECONSTRUCTION ALGORITHM DEVELOPMENT

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Purpose: The role of cone beam computed tomography (CBCT) in diagnostic imaging has expanded significantly as new clinical applications keep emerging. The technical performance of CBCT systems has also improved drastically, driven primarily by hardware developments such as better radiation detectors. However, CBCT imaging still suffers from significant image quality problems and artefacts, caused mainly by imaging geometry, and reconstruction algorithms have not been able to keep up with the demands of improved hardware and expanding applications.

One challenge to developing and testing new CBCT reconstruction algorithms is the lack of test data. Many algorithm developers have to rely on working purely with simulated data, which often lacks many of the physical effects present in actual scanner data, such as scatter and the impact of a poly-energetic X-ray spectrum. In response to this challenge, we have created multiple CBCT open datasets to facilitate and expedite reconstruction algorithm development and testing.

Material and methods: We imaged multiple samples using a CBCT scanner designed and built in-house. The samples range in size from 1 cm to 8 cm, include both organic and inorganic specimens, and form a diverse array of shapes and sizes, suitable for testing the behaviour of reconstruction algorithms in highly varying cases. They include animal bones and soft tissues, insects, seashells, and plastic phantoms cut into various shapes. The scanner uses a 50 kV X-ray tube with a molybdenum target and a Hamamatsu Photonics C7942CA-22 flat panel detector.

Results: Multiple open datasets have been created for distribution via the open-access repository Zenodo. The datasets contain the full flat-field corrected raw projection data as well as metadata on the scanning geometry and scanner settings. Example codes on working with the data in the MATLAB environment are also provided.

Conclusions: In the era of data, CT measurement raw data is also to be shared openly, not held onto. The samples in the open datasets presented here are smaller than most objects encountered in clinical scanning, but for purposes of pre-clinical algorithm development, we believe they form a diverse and highly useful collection.

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ATLAS VALIDATION FOR AUTOMATIC LUNGS SEGMENTATION AND FUNCTIONAL SUBREGIONS IDENTIFICATION IN COVID-19 PATIENTS: AN APPROACH COMBINED WITH QUANTITATIVE DENSITOMETRY

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Purpose: To develop and validate an Atlas-based automated segmentation tool for COVID-19 lungs CT scans at the admission (CT1) and at the follow-up CT (CTfup) at few months after the discharge. To extract quantitative parameter from histograms of manual and automatic contours of CT1 in order to test if significant differences were present. To apply the suggested approach to quantify variations of densitometry parameters along time from the CT1 to fupCT at few months after the discharge in a prospectively followed cohort of patients.

Materials and methods: An Atlas was trained on manually segmented CT1 of 250 patients and validated on 10 CT1 of the training group, 10 new CT1 and 10 CTfup by comparing DICE indexes between automatic (AUTO), automatic-corrected (AUTOMAN) and manual (MAN) contours. A previously developed automatic method was applied on HU lung density histograms to quantify aereted-, intermediate- and consolidated-region. Volumes of subregions in validation CT1 and CTfup were quantified for each method.

Results: In validation CT1/CTfup, manual correction of automatic contours was not necessary in 40% of cases. Mean DICE values for both lungs were 0.94 for AUTOVsMAN and 0.96 for AUTOMANVsMAN. Differences between aerated and intermediate sub-volumes quantified with AUTOVsMAN contours were always <6%. Consolidated sub-volumes showed larger differences (mean:-95±72cc). If considering AUTOMANVsMAN volumes, differences got further smaller for aerated and intermediate, and were drastically reduced for consolidated sub-volumes (mean:-36±25cc). The average time for manual correction of automatic lungs contours on CT1 was 5±2min. Similar results were found also in CTfup. It was pointed out that approaching the CTfup the aerated volume increased and the same recovery trend was obtained by mean lung density which evolved towards air density values.

Conclusions: An Atlas for automatic segmentation of lungs in COVID-19 patients was developed and validated. Combined with a previously developed method for lung densitometry characterization, it provides a fast, operator-independent way to

extract relevant quantitative parameters with minimal manual intervention.

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IN-SCAN REFERENCE SYSTEM FOR RELAXATION TIME MAP RECALIBRATION: EVALUATION OF THE FEASIBILITY IN PHANTOM AND IN VIVO

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Purpose: Accuracy and precision of relaxation time maps represent a great issue in clinical inter-centre and inter-scanner applications, as reported in the literature. We investigated the feasibility of maps recalibration using an in-scan reference system both in a phantom and in an in vivo study, testing two different sequences developed for cardiac applications.

Material and methods: The in-scan reference system consists of twelve vials filled with different concentrations of $MnCl_2$ aqueous solutions. Reference T_1 and T_2 values at 1.5 T were measured with Nuclear Magnetic Resonance (NMR) standard spectroscopic techniques, characterizing their dependencies in terms of both $MnCl_2$ concentration and temperature variation.

We acquired MOLLI (MOdified Look-Locker Inversion recovery) and T_2-prep TrueFISP (Fast Imaging with Steady Precession) maps with a Siemens Aera MRI scanner (1.5 T) of an Eurospin phantom (Diagnostic Sonar Ltd) and of an untrained volunteer with the $MnCl_2$ reference system wrapped around them in a cartridge-like belt configuration. The phantom study was carried out simulating different heart-rates.

The measurement of the $MnCl_2$ reference samples temperature (performed in-scan using an optical fiber sensor) unveiled the ground-truth relaxation times values, thanks to the NMR characterization. A tentative recalibration of the maps of the phantom was performed considering the discrepancy between the NMR-determined values of the reference samples and those measured on the maps.

Results: Considering the phantom study, we found more severe variations due to the different simulated heart-rates for T_2-prep TrueFISP values (up to 60%) with respect to MOLLI ones (< 6%). Moreover, the theoretical expected linear dependence of the relaxation rates (Ri = 1/Ti, with i = 1, 2) with [$MnCl_2$] was preserved only in MOLLI maps. The average discrepancy of -7.5% of MOLLI T_1 values with respect to reference ones was corrected thanks to the recalibration performed on the basis of the in-scan reference system. The recalibration turned out to be unsuccessful for T_2-prep TrueFISP maps. The in vivo acquisitions further support the results obtained in the phantom study: in particular, they pointed out the relevant effect of the non-linearity observed for the T_2-prep TrueFISP results on the recalibration feasibility.

Conclusions: In-scan reference system provides a robust methodology for a quantitative evaluation of mapping sequences reliability, considering the performances in terms of both accuracy and precision. Such systems can be used for the evaluation of the feasibility of recalibration of relaxation time maps, which could lead to intra- and inter-center data harmonization.

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STREAMLINING OF THE QA PROCESS IN A BUSY RADIOLOGY DEPARTMENT

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Purpose: The Imaging Group at the Medical Physics and Clinical Engineering Department at Beaumont Hospital (Dublin) has an extensive QA programme which covers a range of different imaging modalities within Radiology, Cardiology and Theatre. With the increased inventory of X-ray equipment over recent years, medical physicists developed a process to streamline QA scheduling, QA test procedures, report sign-off and circulation to relevant staff.

Methods and Materials: Two pillar methodologies were used to streamline the entire QA process. The first was to standardise QA testing using RTI's X-ray QA Software (Ocean) and the second was to introduce a platform (Microsoft SharePoint) to document and disseminate the resultant QA reports to relevant personnel.

Results: RTI's X-ray QA Software (Ocean) was used to develop test protocols within a variety of imaging modalities such as General X-ray, Fluoroscopy, CT, Mammography and DXA. These standardised templates improved the repeatability of QA measurements year-on-year and made comparisons with baseline values more reliable. The time taken to evaluate, review and electronically sign-off on QA reports through a central portal has significantly reduced - from weeks to days - a key performance indicator (KPI) for the physics QA process.

QA reports are uploaded into an equipment management platform (via MS SharePoint) and shared with relevant staff. This highly configurable platform also allows for scheduling of QA testing and routine servicing. It has also been extremely useful in aiding the documentation and close-out of significant corrective maintenance events such as X-ray tube or digital detector replacement.

Conclusions: Medical Physics staff has introduced two pillar methodologies to restructure the QA process used in the assessment and associated documentation of X-ray equipment within the Hospital. It has improved the reliability of QA test protocols, report sign off and dissemination. It is anticipated that these structures will also facilitate regulatory inspections.

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NORMALISED NOISE POWER SPECTRUM (NNPS) AS A FLUOROSCOPIC SYSTEM OPTIMISATION TOOL

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Purpose: Clinical optimisation of fluoroscopy for Interventional Systems, including the choices of edge-enhancement and noise reduction, is typically performed subjectively by the clinician, radiographer and perhaps vendor clinical specialist. Kenny et al., (2020) [1], using a statistical measure of image quality, calculated quantitative measures of Threshold Detection Index [$HT(A)=1/C.\sqrt{A}$] corresponding to those estimated subjectively using the Leeds TO.10 test object. C is the minimum contrast calculated for an area A. Such calculated values of HT(A) correlated with different levels of applied image processing. Here we demonstrate that the same information on the effects of image processing can be more readily obtained using NNPS.

Materials and methods: In this pilot study three modern interventional systems were examined. Fluoroscopy data were obtained for varying levels of Incident Air Kerma Rate (IAKR), and

with varying levels of edge-enhancement and noise reduction applied. Typically, 50-60 fluoroscopy frames were selected and analysed as described by Kenny et al., (2020). In each case, the squared inverse of the calculated HT(A) values, [$1/HT(A)^2 = C^2.A$], were then plotted against spatial frequency. Corresponding sets of frames were subsequently analysed using a standard NNPS algorithm and the results of both analyses were assessed and compared.

Results: Results obtained show that the shapes of the curves obtained for the NNPS matched those obtained for the inverse of $HT(A)^2$, differing only in the units of the abscissa, thus indicating that both algorithms provide the same image quality information versus spatial frequency.

Conclusion: Inter-comparison of interventional system image quality and the optimisation of system set-up are normally performed subjectively. However, both HT(A) and NNPS offer an objective alternative when comparing systems and optimisations. Both approaches allow the physicist to provide numerical evaluations of the effects of different levels of image processing. However, the NNPS algorithm is more familiar to physicists and thus easier to implement and analyse.

Reference:

[1] https://doi.org/10.1016/j.ejmp.2020.02.002

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PATIENT AND OPERATOR DOSE OPTIMIZATION FOR ERCP PROCEDURES: EXPERIENCE OF A SINGLE CENTRE

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Purpose: Endoscopic retrograde cholangiopancreatography (ERCP) is a procedure that combines upper gastrointestinal endoscopy and X-rays to treat problems of the bile and pancreatic ducts. Our work aimed at assessing and optimizing the exposure of patients and staff to ionizing radiation, in light of ICRP recommendations and European Regulations (BSS 2013), which adopt Diagnostic Reference Levels (DRLs) as an essential tool for the radiological protection of individuals undergoing X-Ray procedures. For operators, dose limits are set in terms of effective (E) and equivalent (HT) doses, that can be estimated from the quantity Hp(d) (personal dose equivalent). We present the results of the survey carried out in our Hospital over a period of 6 years.

Materials and methods: On whole 2890 ERCP procedures were carried out, involving 5 medical doctors, 8 health care assistant and 1 radiographer, using a mobile C-arc X-Ray equipment (MoonRay Simad, Brillance Intensifier 9 inches), subjected to a quality control programme yearly, demonstrating constancy of performance and compliance with the European criteria of acceptability (RP162). Cumulative DAP (Dose Area Product) and fluoroscopy time were recorded for each procedure (DAP meter VacuDAP 2002, VacuTec). Operators wore protective lead apron and collar during the X-Ray procedures. TLD (Thermo Luminescent Dosimeters) calibrated in Hp(0.07) and Hp(10), were used to monitor their exposure (left wrist and upper right region of the chest, over the shielding apron). Hp(d) per procedure and per DAP were estimated for the staff.

Results: Mean value, standard deviation, 50th percentile, minimum and maximum value were respectively: 27,8 – 23,8 – 20,6 – 0,3 and 187 for cumulative DAP (Gy*cm2) and 5,8 – 4,6 – 4,5 – 0,3 – 37,7 for fluoroscopy time (minutes).

Hp(0.07)/procedure was about 90 µSv for medical doctors and 30 µSv for health care assistants;

Hp(0.07)/DAP was about 3 µSv/Gy*cm2 and 0,9 µSv/Gy*cm2 for health care assistants;

Hp(10)/procedure was about 50 µSv for medical doctors and 20 50 µSv for health care assistants;

Hp(10)/DAP was about 2 µSv/Gy*cm2 for medical doctors and about 0,7 µSv/Gy*cm2 for health care assistants.

These values were obtained from the whole data set. The temporal trend of the data showed a decrease of the dose indicators taken into account.

Conclusions: Patient dose data assessed in this survey are consistent with the national DRL.

The data trend demonstrates that the collaboration of the medical physicist with the clinical staff is a key point in order to improve awareness about radioprotection.

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LEARNING EFFECTS IN VISUAL GRADING ASSESSMENT OF NEW RECONSTRUCTION ALGORITHMS IN ABDOMINAL COMPUTED TOMOGRAPHY

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Objectives: The hypothesis was that radiologists could learn to adapt to the unusual appearance of images produced by higher strengths of a computed tomography model-based iterative reconstruction algorithm (ADMIRE) by Siemens Healthineers.

Methods: New analyses of existing data from two previous studies (evaluating the performance of ADMIRE) was performed by introducing the time variable in the ordinal logistic regression model. Visual grading regression was used in the evaluation of specific image criteria in abdominal computed tomography.

Results: For the highest strength of the ADMIRE algorithm, the significant negative attitude for both liver parenchyma and overall image quality at the beginning of the reviews was strengthened during the progress of the reviews in both materials. ADMIRE strength 3 showed an early positive attitude for the algorithm with no significant change over time for majority of the criteria except for one criterion (overall image quality), where a significant negative trend over time was seen in the second material. For the criterion image noise, the opposite was found suggesting that the radiologists appreciated the lower noise with ADMIRE strength 5 more and more.

Conclusions: Radiologists developed a stronger aversion to the image quality produced by ADMIRE 5 as the reviews progressed, reflecting that adaption does not occur and there is no learning effect present.

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PHYSICAL CHARACTERIZATION OF A FAST KVP SWITCHING DUAL-ENERGY CT: PROPOSAL OF A QUALITY CONTROL PROTOCOL

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Purpose: The objective of this study was the implementation of physical characterization measures on a Fast kVp switching Dual Energy CT, for the definition of a quality control protocol compatible with materials and times available in a hospital environment.
Material and methods: A CIRS Multi-Energy CT QA (MECT) phantom was used. The phantom contains a series of five inserts of iodine in blood at increasing concentrations (range 0.5-15 mg/cc), six inserts of calcium in water (range 10-240 mg/cc), two inserts with densities equivalent to muscle and adipose tissues. A Fast kVp switching Dual Energy CT with Gemstone Spectral Imaging (GSI) detectors was used for image acquisition, which exploits a rapid change in kVp between 80 kVp and 140 kVp for each projection. The scans were performed with the following parameters: 280mA, tube rotation time 0.5s, pitch 0.99, helical mode, collimation 40mm, DFOV 50cm, body filter. Reconstructions at different monochromatic energies and concentration maps were sent to the local PACS and processed with ImageJ software. The quantities measured on the phantom images were: concentrations of different materials, effective nuclear charge Zeff, noise and contrast to noise ratio (CNR).
Results: The estimation of the iodine concentration was particularly accurate, with differences between the expected values and the measured values below 5% in the range 2-10 mg/cc. Similar results were found for the calcium inserts. In water and fat samples, the measurement of Zeff was consistent with the expected values (differences below 4%), while on iodine and calcium, as well as on muscle tissue, they were higher with differences between 5 and 12%. The iodine subtraction system was effective with accurate values of water concentrations, thus demonstrating the reliability of reconstruction of virtual no contrast images. In monoenergetic reconstructions, the CNR value motonically decreased with increasing energy, while the noise decreased as the reconstruction energy increases. Measured values were assumed as baseline for subsequent periodic controls.
Conclusions: The quality control protocol used was effective and compatible with the time and staff resources available. It allows to monitor the consistency of the performances of a complex acquisition method that requires high technological standards.

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COMPLEXITY INDICES AND PATIENT DOSE IN INTERVENTIONAL RADIOLOGY

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Purpose: The aim of the study is to establish Institutional Diagnostic Reference Levels (DRLs) according to the complexity indices (CI's) for three interventional radiology (IR) procedures in terms of Dose Area Product (DAP) at the Radiology Department of a University Hospital in Greece.
Materials and methods: Patient's somatometric and demographic data, as well as the exposure parameters were collected from October 2021 to January 2022 for 218 patients who underwent the following IR procedures: Hepatic Chemoembolization (HC) (107 patients), Iliac Stent Placement (ISP) (47 patients), and Femoropopliteal Revascularization (FR) (64 patients). Three complexity indices were assigned to each procedure from interventional radiologists based on the current literature, to extract DRL's for each procedure. HC procedures were classified as ''simple'' (TS≃3), ''medium'' (4≤TS≤5), and ''complex'' (TS≥6). ISP and FR procedures were classified as "simple" (TS≤4), "medium" (5≤TS≤6) and "complex" (TS≥7). Finally, total score (TS) for the complexity was recorded according to the CI's of each IR procedure. Statistical analysis was used to investigate the correlation between dose parameters (DRLs, Reference Air Kerma), exposure parameters and patients' weight.
Results: Somatometric data and exposure parameters were categorized according to the complexity of the procedures (simple, medium, and complex) and a statistical correlation among them investigated.
DAP values for the above three procedures are the following: For HC procedures 80, 137 and 278 Gy·cm2, for ISP procedures 80, 125, 263 Gy·cm2 and for FR procedures 11, 27, and 84 Gy·cm2 respectively. Corresponding KERMA values for HC were 229.57, 583.33, and 2057.10 mGy, for ISP 191.04, 280.45, and 1027.41 mGy and for FR were 56.08, 109.10, and 390.23 mGy. Also, fluoroscopy time values (FT) for HC were 11.33, 13.96 and 20.90 min, for ISP were 3.52, 11.93, and 21.27 min and for FR were 11.92, 15.37, and 30.00 min respectively.
All the exposure parameters were significant related ($p<0.05$) to the complexity of each procedure and patient's somatometric data.
Conclusion: In conclusion, CI's in interventional radiology are a useful tool for the optimization of DRLs, since IR procedures are characterized by high values of doses and fluoroscopy times. DAP, KERMA and FT values were recorded, and statistical analysis revealed the statistically significant differences between them ($p<0.05$).

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PATIENTS WITH SHOTGUN PELLETS IN THE SKULL UNDERGOING MAGNETIC RESONANCE IMAGING: A CASE REPORT

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Purpose: At Gallarate Hospital (VA, Italy) the possibility of carrying out an MRI investigation at 1.5T on a patient with shotgun pellets in the skull and orbits was investigated.
MRI investigation was ordered to investigate possible early sacro-iliac signs from non-radiographic axial spondilo arthritis, which can be excluded with a STIR sequence.
Several Italian medical centers refused to carry out the investigation because of the potential damage from the pellets, especially due to RF induced pellets overheating near critical structures especially inside the orbits.
Methods: Shotgun bullets composition was analyzed (FAAS-XRF) and found to be 95,5% lead, 4,4% antimony and 0,03% copper. Since 99,9% of composition is diamagnetic, significant interactions with the static field were excluded, while overheating from induced electric current was possible.
All preliminary measurements were performed using the same acquisition parameters for the patient (STIR sequences).
First of all, the behavior of a probe thermometer was studied, positioning it in various points inside and outside the gantry.
Pellets were then placed in a spherical phantom, filled with CuSO4 solution, simulating the skull. Measurements of the temperature variation near the pellets were then carried out during the acquisitions.
Result and conclusions: The thermometric probe positioned at the edge of the gantry, where the patient's skull would have been positioned during the pelvic diagnostic acquisition, was not affected

by the magnetic field. Instead, the static field turned off the probe, when positioned inside the gantry.
Inside the phantom, near the pellets, the temperature didn't change significantly (Δt≤0.1 °C). The expected changes within the patient's skull, therefore, should not have caused any damage to critical structures of the optic globes and pathways.
Then, we performed the acquisition on the patient. The radiologist, following the positioning inside the MRI room, asked the patient to report any problems while he was slowly introduced into the gantry. In the absence of reports from the patient, a multiplanar scout view was carried out in the orthogonal directions (GRE TR 4.84 TE 1.33 NEX1). Then a plain coronal STIR sequence focused on sacrum iliac joints (TR 5840 TE 10.84 FA 90 NEX2), capable of excluding bone edema, was performed. Other sequences were planned but not acquired due to claustrophobia.
In conclusion, the team approach of radiologists and medical physicists made it possible to carry out a safe sacrum iliac MRI investigation in a patient with shotgun pellets in the skull and orbits.

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A METHOD TO DETERMINATE THE EXPOSURE NEEDED IN DIFFERENT CONDITIONS TO MANTAIN AN IMAGE QUALITY LEVEL IN DIGITAL RADIOGRAPHY

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Purpose: The task of an automatic exposure control (AEC) system in digital radiography is to terminate exposures when a predetermined amount of radiation has reached the flat panel detector. The amount of radiation used in each case should be kept to the minimum needed to diagnose. Therefore, the anatomic menu should be configured so that a constant image quality is obtained for each task regardless of the patient's constitution and the exposure technique. The aim of this work was to determine the exposure needed in different configurations to maintain a reference image quality for different clinical tasks.
Materials and methods: This work was carried out in a Discovery XR656 system (General Electric, Boston). We simulated 33 different configurations varying the tube voltage (kV) and the thickness of a PMMA phantom (t). Four of them emulated paediatric explorations, nine of them non-paediatric thoracic explorations and eleven of them non-paediatric abdominopelvic explorations. For each clinical task, we choose a reference kV and t: 60 kV-10 cm for paediatrics, 80 kV–15 cm for abdomen/pelvis and 120 kV–15 cm for thorax.
For each combination, we assessed the image quality of six different exposure levels inserting a CDRAD phantom (Artinis Medical Systems, Elst) into the PMMA phantom. The analysis was carried out on the "For processing" images using the software "CDRAD Analyser 2.1.15", resulting in an inverse image quality figure index (IQFinv) for each image. IQFinv were fitted against both the exposure (mAs) and the incident air kerma at the image receptor (Ka,i).These fit functions were used to determine IQFinv,ref for characteristic Ka,i,ref values at reference conditions (2, 2.5 and 3 μGy). Then, the inverse fit functions were used to determine Ka,i (IQFinv,ref;kV,t) or mAs(IQFinv,ref;kV,t) needed to achieve the same IQFinv,ref in the rest of the kV-t combinations.
Results: We found that the best fit for IQFinv against Ka,i or mAs was a biexponential function. We also found that if Ka,i,ref is changed, the ratios Ka,i(IQFinv,ref;kV,t)/Ka,i,ref and mAs(IQFinv,ref;kV,t)/mAsref do not vary significantly (coefficient of variation below 4% for every combination, except for the paediatrics group). This means that a single factor could be computed to determine the exposure needed in other conditions to obtain the same image quality as in the reference conditions.
Conclusions: This work provides a method to determine the exposure needed in non-reference conditions to maintain an image quality level. This information could be useful when adjusting the anatomic menu configuration.

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OPTIMIZATION OF DYNAMIC PEDIATRIC RADIOSCOPY PROCEDURES WITH CONTRAST AGENT REQUIRES NEW TYPES OF PHANTOMS

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Purpose: Optimization in pediatric examinations is of great importance due to the high radiation sensitivity of these patient groups (ICRP 103). Contrast medium is necessary for most of the radioscopy procedures such as abdomen procedures to outline the gastrointestinal lumen against adjacent soft tissues. The purpose of this study was to investigate the specification of adopted phantom for optimization of dynamic procedures.
Material and methods: For pediatric radioscopy, our center uses a dedicated Siemens Healthineer's Artis Zee equipment. For Optimization of image quality in patient examinations sometimes is necessary with change of contrast or procedure performance parameters. Therefore, the optimization team of medical physicist, radiologist, and radiographer need to investigate how image quality correlates to the different contrast agents.
In our optimization work we use different solutions. The contrast agent is placed on the anthropomorphic phantom to simulate some of the organs and the attenuation. The challenge for this phantom is that we need to simulate in dynamic procedures how the contrast is going through the patient, and how it could be matched to the selection of pulse and frames of radioscopy procedures.
A phantom which includes different organs and has possibility for dynamic procedures is necessary for optimization of radioscopy and there is a lack of this dynamic type of phantom. In our center we experimented with prototype concepts to give an idea for design of such a phantom. Our prototype is a play doll which has possibility to "drink" the contrast, such that it can pass through the doll. In this case the doll is not tissue equivalent but an analysis of the phantom regarding contrast between the contrast media and soft tissue in background shows that play doll concept could be a viable prototype design of such a phantom.
Result and Conclusion: The evaluation of the images from the different phantoms was performed by ImageJ software. The signal in the image in a defined region of interest from soft tissue has been compared to contrast media. The results are presented below:
Comparison soft tissue/Barium contrast: Phantom 1 Anthropomorphic 1,38; Phantom 2 Play doll 1,24; differences 10%
The conclusion is that the "play doll" concept has proved promising and warrants the development of a tissue-equivalent prototype for the simulation of dynamic procedure.

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ARM POSITION IN NECK CT SCANS - A PHANTOM STUDY

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Purpose: The arms of the patient should be outside the CT scan range to minimize radiation exposure in CT scans with tube current modulation. However, in neck CT scans part of the arms will be in the CT scan field independent of the arm position. The aim of this study was to examine how the arm position affects tube current modulation and therefore patients dose.

Materials and methods: CT scans of the neck were performed on an Alderson Phantom. As arms were not part of this phantom, upper arms were created, matching attenuation properties of real arms. Localizer settings and arm position were varied in the CT scans and tube current modulation (TCM) and image quality was assessed.

Results: When the arms were lying beside the body the dose was higher than when the arms were lying beside the head. When the arms were beside the head the TCM-curve dropped in the thoracic region of the phantom and raised in the neck and head region but in mean the dose was lower. Greater differences on image quality were especially in body regions with many bony structures as in the shoulder region.

Conclusions: An arm position beside the body showed in mean a 13% higher dose than an arm position beside the head when using an localizer in ap position. However detailed evaluation of TCM curves showed that the distance of the arms to the x-ray tube in the localizer had the greatest impact on TCM.

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THE USE OF A VTAC 4000K LED FLOODLIGHT FOR INDOOR WHITE LIGHT PHOTODYNAMIC THERAPY

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Purpose: Daylight or artificial White Light sources Photodynamic therapy (PDT) are used as an alternative to traditional red light PDT. The blue and red wavebands of the white light activate a light sensitive pharmaceutical, 5-methyl aminolaevulinic acid (PPiX) which is topically applied to patient's skin area requiring treatment. White light is a more easily tolerated treatment method due to the relatively low intensity of the activation wavelengths present in white light spectrum. Commercial white light PDT uses expensive high powered lights to achieve similar treatment outcomes when compared with red light and daylight PDT. An outdoor floodlight treatment device has been set up and tested with the aim of providing a white light treatment.

Material and methods: The operating principle behind the device is that there is high amplitude of red and blue light from the device in wavebands where a strong specific absorption of PPiX occurs. Furthermore the highly uniform output of the outdoor floodlight allows large areas to be given a consistent and repeatable exposure. The Light was mounted on a height adjustable stand facilitating skin dose rate adjustment and included an integrated timer and patient monitoring device. The device was risk assessed for patient and occupational hazards including optical radiation. Patient and Staff PPE were also specified. This indoor treatment device allows for more consistent and reproducible light dose delivery throughout the year.

Results: The flood light provides a reasonably uniform irradiance of 44 mWcm2 of visible white light at 50 cm from the source, facilitating treatment of areas up to maximum area of 25cm2. A red light dose of 53 J/cm^2 in 120 minutes with a PPIX weighted dose of 7 J/cm^2

Conclusions: This study demonstrates that the use of an outdoor floodlight with an appropriate spectrum and uniformity can provide white light photodynamic therapy of an equivalent performance to high cost commercial units.

POSTER ABSTRACTS –E&T

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RADIATION SAFETY TRAINING IN IRELAND: WHERE ARE WE NOW AND WHERE ARE DO WE WANT TO BE?

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Requirements for radiation protection education, training and information in EU member states are outlined in Chapter IV (Articles 14 to 17) of COUNCIL DIRECTIVE 2013/59/EURATOM. These requirements are articulated in Irish law under two separate regulations:

- Regulation 35 of SI 30 (2019), regulated by the Envionmental Protection Agency (EPA), relating to worker and public safety
- Regulation 22 of SI 256 (2018), regulated by the Health Information Quality Authority (HIQA), relating to patient safety.

In the case of occupational radiation safety training (Reg 35), it is the responsibility of the undertaking or employer to ensure that relevant employees "are given appropriate education, training and information in the field of radiation protection". This is similar to the previous legislation (SI 125 (2000)) and training is usually given by the undertaking (e.g. hospital) and recorded locally for regulatory evidence.

In the case of patient radiation safety (Reg 22), it is the responsibility of the undertaking to ensure that practitioners and delegated individuals "have adequate education, information and theoretical and practical training for that purpose, as well as relevant competence in radiation protection". The training must be prescribed by the relevant professional training body, specified in the regulation, "having regard to the European Commission's Guidelines on Radiation Protection Education and Training of Medical Professionals in the European Union (Radiation Protection (RP) No. 175)". Whilst RP 175 specifies the Knowledge, Competence and Skills for different professional groups, to date none of the professional bodies stipulated in the regulation have formally prescribed the training required. Considering this, HIQA has delayed the regulation of training until such time as the professional bodies agree an appropriate programme syllabus and design.

In the interim what are undertakings to do with regard to the training of practitioners and delegated individuals? Under previous regulations (SI 478(2002)) training approved by the Medical Council, would have been provided by medical physicists in collaboration with radiology specialists.

This presentation describes the current status of radiation safety training in Irish public hospitals and examines what it may look like in the near future. It also outlines the approach taken by one Dublin Hospital, with respect to providing occupational radiation safety training to meet EPA requirements, and "interim" practitioner and delegated individual radiation safety training, having regard to RP 175, to meet HIQA requirements.

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RADIATION SAFETY E-LEARNING TRAINING FOR NON-RADIOLOGY DOCTORS AND OTHER STAFF: EXPERIENCES IN A MAJOR ACADEMIC TEACHING HOSPITAL

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Purpose: Requirements for radiation protection education, training and information are articulated in Irish law under two separate regulations:

- Regulation 35 of SI 30 (2019), regulated by the Environmental Protection Agency (EPA), relating to worker and public radiation safety
- Regulation 22 of SI 256 (2018), regulated by the Health Information & Quality Authority (HIQA), relating to patient radiation safety.

These require the undertaking (e.g. hospital) to ensure that workers have relevant radiation safety knowledge, competence and skills to carry out work with ionisng radiation. This presentation describes the experience of using an in-house e-learning program to provide radiation safety knowledge training to all relevant staff.

Material and methods: Mandatory online training programmes, e.g. manual handling and fire safety, are widely available in the hospital and completion of periodic mandatory training is recorded for each member of staff. In consultation with the radiation protection adviser, medical physics expert and radiation protection officer, an online radiation safety training programme was designed and implemented using the available tools (i.e. Adapt builder® on www.learningpool.com). The HR department, in consultation with the radiation safety committee (RSC), agreed:

- To implement the radiation safety programme as a mandatory programme for selected staff groups, with a refresh every 3 years.
- That all new non-radiology doctors would receive an email with their job offer, weeks before they start, indicating that they must complete the online training before starting work.
- That access to the PACS/RIS system would be restricted to those doctors who have completed the e-learning training programme.

Results: The programme was formally implemented and provided to 360 staff members, including non-radiology doctors in 2020 and 2021. The completion rates for different directorates within the hospital were captured. The overall completion rates for all relevant staff are 63% for 2020 and 69% for 2021.

Completion rates for non –radiology doctors in different directorates (i.e. in TUN, Surgical, Medicine, Neurocent, Critical Care & Anaesthetics) were lower on average and decreased for all but one directorate year on year.

Conclusions: Future work will look at increasing radiation safety training completion rates through sustained communication with directorate heads and other stakeholders.

The training completion rates for all groups and individuals are available for regulatory review.

The content of the knowledge based training modules can be updated and tailored to any future requirements that may be prescribed by the relevant professional bodies.

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'POINT OF CARE' RADIATION PROTECTION TRAINING

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Purpose: The European Basic Safety Standard (2013/59/Euratom) requires that all staff who are categorised as radiation workers must be provided with radiation safety training. The inexorable rise in the clinical use of ionisation radiation, combined with increasing waiting list and high staff turnover, has inevitably made it increasingly difficult to meet this requirement using the traditional training approach. Against this background, the Medical Physics and Clinical Engineering (MPCE) Department at Galway University Hospitals decided to investigate this problem using modern solutions and methodologies.

Material and methods: Smartphones, QR codes and their associated technologies provide modern solutions to this 'long standing' problem. This technology enabled us to provide training at the 'point of care'. A QR code provides a unique URL address. When the clinical staff scans the code they are directed to a web page which contains a competency assessment, and multimedia training material. In addition, a real time system to 'track and trace' users' attendance and competency level is available.

Results: In an initial trial over a sixteen week period ninety eight (98) staff members voluntarily accessed the 'point of care' RP training module, passed the assessment and received certification. A wide range of staff including, Nurses, SHO's, Senior Registrars, and Consultant Vascular Surgeons accessed the training at various times during a 24-hour period. To date Radiographers and Nurses account for 18% and 19% respectively, of the total number that engaged with the training. Staff at Consultant level account for only 1% of the total trainees. The average score on a post-training competency based assessment of 10 questions is 85%.

Conclusion: Analysis of the attendee data has highlighted clinical disciplines and knowledge gaps which feed into the next iteration of the training module. Initial positive feedback has been received from staff who have engaged with the system over the period, and we are in the process at present of 'rolling' this programme out across the west of Ireland region. The live data allows the radiation protection team to 'take the temperature' of one aspect of the radiation safety culture of the hospital. It does not replace 'face to face' radiation safety training, but it does provide a new tool to address the long standing problem of staff engagement with radiation safety training.

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LESSONS LEARNT FROM 20 YEARS OF MEDICAL PHYSICS EDUCATION AT THE NATIONAL UNIVERSITY OF IRELAND GALWAY

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The MSc in Medical Physics program was established in NUI Galway in 2002. The program is designed with a 90 ECTS module structure over a one year period. The founding clinical director, the late Prof Wil van der Putten, recognised the need for an MSc program to compliment the training and education of Medical Physicists. To create a clear educational pathway an undergraduate stream in Medical Physics was established in 2007. Undergraduate physics programs at NUI Galway are accredited through the Institute of Physics (IOP) and the MSc program was the first European program to received CAMPEP (Commission on Accreditation of Medical Physics Education Programs) accreditation in 2015. The accreditation of the program has led to a rapid increase in the number of applicants and also the diversity of these applicants.

The MSc programme is an excellent example of a multidisciplinary and multi-institutional effort. The success of the programme is been driven predominately by the close collaboration of the hospital physicists supplemented by University staff. The success of the program presents opportunities but also challenges in terms

of delivery especially for hospital based components and research projects. The benefits of diversity in higher education has been studied widely and there is significant opportunities to champion diversity in the national and international Medical Physics community.
Physics has one of the most notable gender disparity ratios of all disciplines. Studies in North America have shown 20% of bachelors in Physics and 19% of doctoral degree graduates are female. However gender diversity in Medical Physics is much better with approximately 30% of Medical Physics positions held by females globally. Medical Physics as a discipline can provide leadership in equity, diversity and inclusion (EDI) and this begins in our outreach and education programs.
Medical Physics can play a major role in EDI in education and gender diversity in higher education is one key aspect. As an example, out of the last 120 students enrolled on the MSc in Medical Physics at NUI Galway 46% were female, which is in stark contrast to the 20% female uptake typically seen in physics programs. A lot more can be done on all aspects of EDI including salary inequity, mentoring programs, unconscious bias training, gender blind reviews of all awards, proposals and publications. However, as a Physics sub-discipline Medical Physics is going the right direction.

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ENEN# - BUILDING EUROPEAN NUCLEAR COMPETENCE THROUGH CONTINUOUS ADVANCED AND STRUCTURED EDUCATION AND TRAINING ACTIONS

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Purpose: Education and training (E&T) in nuclear matters in Europe need persistent efforts to be adequately promoted, aiming to maintain and further develop the high level of expertise reached in the nuclear power and non-power fields and also in considering the limited attractiveness of nuclear careers for young generations, experienced both at universities and in recruiting for jobs.
Material and methods: The European Nuclear Education Network (ENEN), since its establishment in 2003, has had "the main purpose of the preservation and the further development of expertise in the nuclear fields by higher education and training", counteracting difficulties that, with alternate fates, have been experienced in the last two decades. In almost twenty years of its existence, ENEN has deployed efforts in support to E&T in nuclear sectors, with the continuing contributions to EU projects, organising the most important actors in the E&T and cooperating with technological platforms and industrial bodies.
Results: Higher number of nuclear talents will be attracted through dedicated career events and competitions for high school pupils and teachers, students (BSc, MSc, PhD), postdocs and lifelong learners. A strong mobility program will support over 100 person-years of nuclear career enhancing experience to about 1,000 learners with over 2.5 million EUR.
Cross-border and cross-disciplinary mobility within and beyond the EU will be promoted in cooperation with JRC, OECD/NEA and partners from the USA, Canada, China, Korea and Japan. A single hub will be established to provide information on available educational, training and job opportunities. Appropriate connections with the complementary NRT-12 project facilitating access to research infrastructures will be established. The project ENEN# integrates the still fragmented European E&T community by bringing together a large number of participants from all nuclear energy related fields (nuclear engineering and safety, radiation protection, radioactive waste management, medical applications, nuclear safety culture, nuclear safety management, radiochemistry, decommissioning and nuclear safeguards).
Conclusion: The ENEN# project has 55 project partners, between them we can find larger European organisations like ENS (European Nuclear Society), EFOMP (European Federation of Organisations for Medical Physics), FORATOM (European Atomic Forum), OECD-NEA (Organisation for Economic Co-Operation and Development), JRC (European Commission Joint Research Centre) and several universities.

POSTER ABSTRACTS – INFORMATICS (IT)

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INTRODUCING MYCO (MONTY CARLO) – A CYTHON POWERED MONTE CARLO PYTHON FRAMEWORK FOR THE SIMULATION OF PARTICLE TRANSPORT FOR MEDICAL PHYSICS APPLICATIONS

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Purpose: Monte Carlo methods have become a reference in many radiotherapies, radiodiagnostic and nuclear medicine dosimetric calculations. Many state-of-the-art commercial codes are available to end-users in clinical, research, and academic environments. Understandably, the developers of these codes chose statically typed, compiled languages for their high-performance implementation. This choice, however, comes with the unfortunate consequence of forcing the end-user to write code in those very same languages.
The modern landscape of the software development industry is permeated by high-level, dynamically typed, interpreted languages because they yield platform-independent software with considerably less effort. React, React Native, and Electron.js are JavaScript frameworks used by multi-billion-dollar companies. Their outputs can be seen everywhere: Discord, Slack, Microsoft Teams, and Twitch are just some popular examples.
This project's purpose is to bring the practices and innovations of the software industry to the field of Monte Carlo simulations of radiation transport. It aims to allow users to quickly build the geometry in a new Python syntax inspired by Reacts JSX and run the simulation in highly optimized Cython code while enjoying the benefits of platform-independent production code. All this, without touching any compilation tools during development.
Materials and methods: The particle interaction simulation package was written entirely in Cython, a superset of the Python language that supports calling C functions and gives similar if not better performance. Currently, MyCo can simulate photon and electron/positron transport in any medium using the EADL, EPDL, and EEDL databases. The code uses well-established models such as the Sternheimer-Liljequist generalized oscillator strength model, a random-hinge condensed history model, and an atomic relaxation model based on the EADL vacancy transition probabilities. Particles tracks and geometry are simulated using a mix between Ray Tracing/Ray Marching, optimizing interface treatment.
Results: PDD calculations using MyCo and comparing it with other available codes (MCNPX, PENELOPE) show optimal code implementation. MyCo can accurately simulate photons, electrons and positrons in any medium. Computational models very accurately predict the electron stopping power and the characteristic Bremsstrahlung radiation.

Conclusion: A move from low-level compiled languages for Monte Carlo simulations is possible. End-users can enjoy the advantages of working with an interpreter language with access to all other python modules (NumPy, scipy, pandas, matplotlib.). This vastly increases the versatility of MyCo, creating an enormous potential for this code to be used not only in academia but also in research and clinical environments.

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CENTROIDAL VORONOI TESSELLATION FOR LOW CONTRAST DETECTION AND SUPER-RESOLUTION IN PHANTOM CT IMAGES

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Purpose: The detection of low contrast objects in computed tomography (CT) images is a crucial aspect in order to optimize the CT acquisition protocols, reduce the patient dose and thus fulfill the ALARA principle. The purpose of this work was the development and evaluation of an algorithm based on the combination of the Centroidal Voronoi Tessellation, an image analysis technique commonly employed in the astrophysics field, and machine learning approach, optimized for the detection and resolution enhancement of low contrast objects.
Material and methods: Several CT acquisitions were collected on a polymethylmethacrylate (PMMA) phantom, containing five cylindrical inserts of different diameters filled with iodinated contrast media at two concentrations, in order to generate 15 and 20 HU of signal difference with the background. The phantom was repeatedly scanned using a clinical CT scanner at various CT Dose Index (CTDI) and various angles respect the z axis, selecting the standard protocol for abdomen. The images were then processed with an original algorithm based on Central Voronoi Tessellation, which makes use of the McQueen algorithm. The result of this process is a rebinning of the pixels, creating some cells inside the image having a smaller area where the signal sought is more intense. Finally, in order to correctly identify the signal from the background, both thresholds on the cells area and a non-supervised machine learning algorithm were used. The signal search was carried out for each axial slice, in order to combine thereafter, in a unique 2D image, the information carried out from the third dimension, thus performing a "2.5D" procedure.
Results: In general the signal detection success rate was found to be greater than that of the human observer. In addition, the barycenter of the signal, found in each slice, allowed the correct identification of the axis of the object in the third dimension. As last, a super-resolution 2D images, obtained by the sum along the axis previously identified, was generated in order to obtain an increased SNR respect to the one obtained summing over the conventional z-axis.
Conclusions: The Voronoi tessellation, an already well established technique in astrophysics, provides excellent performances in the search for low contrast objects in CT images. This algorithm appears to be very promising for future development, aimed at supporting the diagnosis of lesions in homogeneous organs, such as the liver.

POSTER ABSTRACTS – NM

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AN EXPERIMENTAL AND MONTE CARLO EVALUATION OF THE IMAGING PERFORMANCE OF A PIXELATED SPECTROSCOPIC TIMEPIX3 IMAGING DETECTOR

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Purpose: Full Field Digital Mammography (FFDM) is an established high spatial and contrast resolution modality, and represents the gold standard with which other emerging detector technologies may be compared. The recent development of event-driven detectors such as the Timepix3 (TPX3) has allowed for photon energy measurement and more precise event localisation, resulting in improved spatial and contrast resolution. The purpose of this research was to compare the imaging performance capabilities of the TPX3 versus a state-of-the-art FFDM unit.
Material and methods: A combination of experimental and Monte Carlo (MC) methods were used to compare the performance of a TPX3 detector with a 1 mm Cadmium Telluride (CdTe) active sensor and a Hologic 3D Dimensions a-Selenium (a-Se) FFDM system. The slant edge technique was used to determine the Modulation Transfer Function (MTF) of the TPX3 and FFDM unit for a range of parameters including FFDM tube voltage (kVp) and TPX3 bias voltage. The acquisitions were carried out with and without the presence of a number of 1 cm thick slabs of polymethylmethacrylate (PMMA) to simulate different breast thicknesses and evaluated the effects of scatter. The effect of TPX3 energy window selection and its potential to reduce the effects of scatter was also investigated. An EGSnrc MC model of the TPX3 detector was developed to validate the experimental data and to describe the response of the detector under different constraints.
Results: The measured MTF of the TPX3 at 50% (6.79 lp/mm), in addition to the contrast to noise ratio, were consistently higher than those of the FFDM system for all parameters (kVp, scatter), suggesting that employment of the TPX3 detector can potentially result in an improved imaging performance. The TPX3 MC simulations were in agreement with the experimental data (50% MTF = 6.70 lp/mm) where no scatter media was present. For cases where PMMA was present, experimental and MC simulations show that for low kVp, scatter corrections via spectrum windowing does not impact the MTF significantly. However, for higher kVp and increased scatter medium, energy spectrum corrections do improve the MTF and, consequently, enhances the image quality.
Conclusions: The image quality metrics evaluated demonstrated that the TPX3 offers an improved imaging performance over that of the FFDM unit, with further scope for improvement in clinical imaging through the use of the TPX3's energy resolution and spectral windowing.

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DIAGNOSTIC AND DOSIMETRY FEATURES OF 64CUCL2 IN HIGH-GRADE PAEDIATRIC INFILTRATIVE GLIOMAS: A FIRST STEP TOWARDS THERAGNOSTIC APPLICATIONS

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Background: Paediatric diffuse high-grade gliomas (PDHGG) and diffuse intrinsic pontine gliomas (DIPG) are rare and aggressive central nervous system neoplasms; effective therapeutic options are lacking. Molecular imaging of tumour metabolism might provide novel insight into the biology of these tumours and potentially identify therapeutic targets. In this study, we tested the diagnostic effectiveness, the biodistribution and the dosimetric features of 64CuCl2.
Methods: Paediatric patients with pathologically proven PDHGG or with DIPG according to clinical and MRI criteria were prospectively recruited. In all patients, 64CuCl2 PET/CT was performed one hour after tracer injection; if the scan was positive, it was repeated 24 and 72 hours later. Lesion SUV and target-to-background ratio (TBR) were calculated at all time-points. Tumour and organ dosimetry were calculated by means of the MIRD algorithm. Each patient underwent an MRI scan, including FLAIR, T2-weighted and post-contrast T1-weighted images.
Results: Ten patients were enrolled (median age 9). Six patients had visible tracer uptake on the PET images (SUV: 1.0±0.6m TBR: 5.0±3.1). 64CuCl2 accumulation was always concordant with the presence of contrast enhancement on MRI; moreover, uptake indices were higher in the presence of radiological signs of necrosis. Specifically, both SUV and TBR increased on the 24h and 72 h acquisitions ($p<0.05$ and $p<0.01$, respectively). The dose to the organs correlated inversely with body weight, while the tumour dose was independent from this parameter.
Conclusions: 64CuCl2 is a safe tracer, showing selective uptake in tumour areas with visible contrast enhancement and necrosis, and an accumulating trend over time. These characteristics could enable the use of this tracer in identifying the most aggressive tumour component, and potentially allow dosimetry and theragnostic approaches.

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WHOLE-BODY DOSIMETRY OF 131I-MIBG FOLLOWING HIGH-GRADE PAEDIATRIC NEUROBLASTOMA FIRST TREATMENT

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Background: Neuroblastoma (NB) originates, as a primary tumor, of the sympathetic nervous system and it is the most frequent extra-cranial solid neoplasm in the paediatric age. Here we focus on the radionuclide therapy of NB with 131I-MIBG, whereby bone marrow toxicity limits the amount of administered activity and thus the therapeutic tumor dose.
Methods: The MIRD protocol is used to calculate whole-body absorbed doses following 131I-MIBG first therapy in children with NB. Whole-body dosimetry is a replacement for bone marrow dosimetry, as the latter may require long procedures, which could be invasive, especially for paediatric patients.
Results: There is a high linear correlation between the whole-body dose and the activity/kg. An injected activity higher than 500 MBq/kg led to a non-trivially estimable whole-body absorbed dose, which is seen to vary from 1.63 Gy to 4.23 Gy. We observed a power law correlation between the whole-body absorbed dose per unit activity (D/A) and the patient body weight (W).
Conclusions: We recommend compliance with the value of 444 MBq/kg to keep the average whole-body dose at 2 Gy, in anticipation of a second dosimetry-based infusion to reach a cumulative dose of approximately 4 Gy. The D/A trend as a function of W can be used in a first approximation for the choice of the activity to be administered.

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VERIFYING CORRECT OPERATION OF AN EXTERNAL PROGRAM FOR INTERNAL DOSIMETRY: PRELIMINARY REPORT

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Purpose: The implementation of routine internal dosimetry in clinical nuclear medicine departments which provide targeted therapies may improve their efficiency. Purchased commercial external dosimetry program for internal dosimetry is a “black box” for users. Implementation of the internal dosimetry program for clinical purposes should be preceded not only by the calibration recommended by the software manufacturer but also by a series of phantom tests confirming the correctness of the calibration and operation of the program for calculating absorbed doses. The study aimed to check the accuracy of the settings and operation of the Q.Dose - an external program for internal dosimetry.
Material and methods: The study began with sensitivity measurements of two SPECT/CT systems: NM/CT 850 gamma camera with Xeleris software from GE Healthcare and Symbia Intevo Bolt gamma camera with Syngo.via software from Siemens. Then SPECT/CT acquisitions were performed for the NEMA IEC Body Phantom with 6 hot spheres of different diameters: 10 mm, 13 mm, 17 mm, 22 mm, 28 mm, and 37 mm. The phantom was filled with a water solution of 99mTc which had initial total radioactivity of 970 MBq measured with activity meter Capintec-55tR. The ratio of radioisotope concentration in the spheres to the concentration in the cylinder was 8:1. Two series of images were performed using both gamma cameras in succession. After preparation, the phantom acquisition was performed, 3 times on the same day and 2 times on the next day, with both gamma cameras. The obtained image series were analyzed using Q.Dose software. Phantom slices were reconstructed using qualitative as well as quantitative image reconstruction methods.
Results: Time Activity Curves (TACs) were obtained for the performed series of measurements. For gamma camera NM/CT 850, the correct activity measurement results for all time points have been obtained with the reconstruction with Q.Volumetrix software. The proper results of activity measurements were obtained after setting the unit of activity concentration kBq/ml in the Q.Dose program. For the gamma camera Symbia Intevo Bold, the correct TAC can be obtained for the standard method of image reconstruction. Image reconstruction with the xSPECT technique should not be used before dosimetric calculations.
Conclusions: Purchased commercial external software for internal dosimetry is a “black box” for clinical users. Before clinical implementation, it requires proper calibration and adjustment to imaging scanners. Phantom measurements are needed to check the correctness of the obtained dosimetric reports.

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DEVELOPMENT OF AN ICTAL SPECT SERVICE FOR IRISH EPILEPSY PATIENTS

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Purpose: Beaumont Hospital (Dublin) is a large academic teaching hospital and specialist centre for complex epilepsy and epilepsy surgery. Ictal SPECT is a unique Nuclear Medicine examination that can be used as a tool in pre-surgical localisation of an epileptic focus. During a seizure there is hyper perfusion in the epileptogenic focus. While the patient is being EEG monitored in the Epilepsy Monitoring Unit (EMU), rapid injection of a brain perfusion radiopharmaceutical at seizure onset followed by ictal SPECT imaging can provide the epilepsy surgical team with more specific localisation information to aid presurgical planning.
In view of the potential benefits to epilepsy patients an Ictal SPECT service has been established in Beaumont Hospital. There are many challenges and complex issues to address when developing a routine Ictal SPECT service in order to provide a quality and safe service to patients and staff. A multi-disciplinary approach was taken when planning and developing this new service in Beaumont Hospital.
Material and methods: This procedure is carried out between the following departments: Nuclear Medicine Department, Neurology, the Epilepsy Monitoring Unit (EMU) and Neuro Physics.
The following areas required careful development and planning for the project:
(1) Patient Selection and Preparation:
(2) Radiopharmaceutical Selection, Preparation and Dispensing:
(3) Nuclear Medicine Radiation Protection Issues:
(4) Patient monitoring and administration of Radiopharmaceutical on the EMU:
(5) Nuclear Medicine Patient Scanning:
(6) Data Post Processing (SISCOM):
A site visit to UZ Leuven hospital Belgium occurred early in the project, this provided invaluable information and support from an experienced centre with a long established Ictal SPECT service.
Results: There have been many unexpected challenges during the establishment of this service:
- Supply issues of the Radiopharmaceutical tracer
- The impact of Covid-19
- An issue with absorption of the radiopharmaceutical within the Delivery tubing system

To date two patients have successfully undergone Ictal SPECT exams, both were administered the radiopharmaceutical within seconds of the onset of a seizure. The results of the Ictal SPECT exam were discussed at a multi-discipline meeting and were used in the patient pre-surgical planning.
Conclusions: Ictal SPECT is an intricate procedure that requires extensive planning and co-operation between the multi-disciplinary team in order to provide a quality and safe service to the patient. Beaumont Hospital hopes to continue and expand this service.

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DEPENDENCE OF MICRODOSIMETRIC QUANTITIES ON DIFFERENT GEOMETRICAL PARAMETERS FOR RADIOPHARMACEUTICAL ALPHA EMITTERS

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Purpose: Radiopharmaceutical therapy (RPT) uses radiolabeled agents affine to biomolecules overexpressed in tumor cell environments. This type of treatment has the potential to improve outcomes for oncologic patients due to its ability to concentrate radiation in a small environment around the tumor.
In particular, this work focuses on alpha-particle emitters for RPT. The use of this particle is based on the much higher linear energy transfer (LET) of the alphas emitted together with their considerably shorter range as compared to beta emissions. Interestingly, microdosimetry can help in the assessment of the biological effect of these particles to fully take advantage of the features mentioned above. This work studies the impact of different cell geometries on the microdosimetric distributions considering the nucleus as the relevant target.
Material and methods: We studied how the microdosimetric quantities are affected by the displacement of the cell nucleus, and variations in the nucleus and cell radius, assuming an uniform distribution of radioactivity across spherical cell membranes. Previously, an analytic algorithm was developed to calculate microdosimetric quantities (yF, yD, zF, zD) for the mentioned setup [Bertolet et al. Radiat. Res.(2020)]. Besides exploring the influence of the eccentricity and radius of the nucleus and cell, we tested the capability of the analytical algorithm to predict microdosimetric quantities for different cell and nucleus radii and eccentricity of the nucleus within the cell. To calculate the distribution of these microdosimetric quantities, Monte Carlo simulations were run using the Geant4 toolkitwith its extension Geant4-DNA.
Results: Our preliminary results show that, as long as the cell radius is not comparable to the range of the alpha particle emitted, microdosimetry quantities are not affected significantly by the cell nucleus position. However, as the cell radius increase, the dependence on the nucleus position become more significant. In all cases, the analytical method agrees reasonably well (< 10%) with the Geant4 simulations.
Conclusions: From the preliminary results we can state that for cases where the cell size will not be comparable with the range of the alpha emitted by the cell membrane, the displacement of the nucleus within the cell can be disregarded. This phenomenon can help to simplify future studies with radiopharmaceutical alpha emitters.

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EVALUATION OF THE CONTAMINATION DROPLET MODEL USED FOR THE RISK ASSESSMENT OF SKIN DOSE DURING THE MANIPULATION OF RADIOPHARMACEUTICALS

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Purpose: During the manipulation of radiopharmaceuticals in nuclear medicine, it is reasonably foreseeable that an operator could unknowingly spill a droplet of the solution on their gloved hand and, depending on the radiopharmaceutical, accumulate a significant skin dose. In the UK, the potential dose resulting from this situation should be estimated and recorded in a radiation risk assessment for compliance with the Ionising Radiation Regulations (IRR17). Published radionuclide data handbooks utilised both analytical and simulation-based methods to estimate the skin dose rate for this accident scenario. Both methods modelled a contamination

droplet as a 0.05 cm^3 cylinder, resulting in relatively high skin dose estimates for some radiopharmaceuticals.
Material and methods: This project evaluated whether a 0.05 cm^3 cylinder is a realistic contamination droplet model by conducting experiments to measure the size of real droplets that arose during the simulation of the manipulation of radiopharmaceuticals. With this, the skin dose rates for 11 commonly used nuclear medicine radionuclides were re-evaluated using Monte Carlo simulations and compared to previously published values. The resultant skin dose rates were used to calculate equivalent skin doses from contamination droplet incidents for 10 radiopharmaceuticals.
Results: The largest foreseeable contamination droplet resulting from the manipulation of radiopharmaceuticals was measured as having a volume of 0.01 cm^3. Utilising this droplet model in Monte Carlo simulations resulted in dose rates which, for almost all radionuclides, were significantly different to published results utilising a 0.05 cm^3 droplet model, thus highlighting the need to model the droplet geometry accurately. Incorporating the measured dose rates into equivalent skin doses for incident scenarios resulted in lower doses for almost all radiopharmaceuticals compared with doses acquired from published skin dose rates.
Conclusions: This project found that the 0.05 cm^3 droplet model used to estimate skin dose by previous publications is an over-estimation of a realistic contamination droplet volume. For almost all the radiopharmaceuticals considered, incorporating a smaller droplet volume into skin dose simulations resulted in higher estimates of skin dose rate per unit of activity, which when combined with activity concentration and droplet volume resulted in lower equivalent skin doses for contamination droplet incidents. The results presented in this project can be adapted for specific incident scenarios and implemented into radiation risk assessments.

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INVESTIGATING MONOLITHIC-DETECTOR PET DESIGN BY DIRECT SIMULATION OF SCINTILLATION PHOTONS AND EVALUATION OF ITS IMPACT ON IMAGE RECONSTRUCTION

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Purpose: The use of monolithic scintillating crystals in PET detectors has recently become a promising alternative to conventional pixelated crystal-array designs due to a demonstrated potential increase in sensitivity and intrinsic spatial resolution. Investigating monolithic-detector PET systems by using well-known Monte Carlo (MC) simulation and image reconstruction tools is currently a laborious multistep process involving software integration and significant computational requirements. The task entails the challenges of efficiently and realistically simulating scintillation photons, incorporating algorithms for gamma-ray point of interaction (POI) estimation and generating list-mode data for image reconstruction. Given the potentiality of monolithic detectors, and in light of the long-term intended development of multimodal detectors, an integrated simulation and reconstruction scheme was developed for the investigation of monolithic-detector PET systems. In-depth analysis and optimization of subprocesses and parameters of said systems become thus possible by addressing the aforementioned challenges with an efficient simulation and reconstruction procedure.
Materials and methods: Initially, a MC simulation of a positron source distribution in a monolithic-detector PET scanner layout is implemented in Gate (Opengate collaboration) and gamma-ray POI list-mode data is stored. Coincidence-sorted POIs are then used as emission points for scintillation-light distributions simulated within the monolithic crystals using an in-house developed MC simulator for optical photons. Subsequently, the gamma-ray POIs, only known in simulations, are estimated from light flux projections on the crystal's photosensing faces (e.g. single-face, co-planar, right-angled arrangements) with a k-nearest neighbours machine learning algorithm. Estimated POIs are finally used to create list-mode data suitable for tomographic image reconstruction, currently implemented with the CASToR toolkit via discretized 1 mm^3 crystal sampling.
Results: A preclinical monolithic-detector PET system was studied and compared to a conventional pixelated crystal-array scanner of similar size. Geometrical features and crystal optical characteristics were investigated, compared and optimized based on their effects on scanner performance and image quality. Point-source phantom studies indicate reconstructed-image spatial resolution capabilities of 1 mm FWHM.
Conclusions: The simulation and reconstruction scheme developed was shown to be a useful and comprehensive tool for the study of monolithic-detector PET systems. The performance of scanner layouts can be efficiently evaluated and specific aspects of monolithic-detector PET systems thoroughly investigated. Furthermore, current efforts aim at implementing an image reconstruction algorithm able to directly utilize real-value POIs without the need of crystal discretization. This work strives to contribute to the transition towards monolithic detectors for the advancement of PET systems and the development of new multimodal techniques.

POSTER ABSTRACTS – PROFESSIONAL MATTERS

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BLUE LIGHT EXPOSURE IN MEDICAL IMAGING: RISK ASSESSMENT FOR MEDICAL AND HEALTH PROFESSIONALS EXPOSED TO LED MONITORS VISIBLE OPTICAL RADIATION

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Purpose: In recent years, possible health risks induced by blue light emitting devices have gained a lot of attention, mainly because of their large increase in use. Numerous studies demonstrate how exposure to blue light causes photochemical retinal damages to the eye, and some suggest it constitutes one of the factors leading to Age-related Macular Degeneration (AMD). In addition, studies show how blue light have a negative effect on the regulation of circadian rhythm. In this context, the present work addresses the wide use of medical monitors by medical and health professionals during reporting, and aims to perform a complete evaluation of blue light exposure levels generated from LED monitors through a spectral characterization on these devices and a standard method for risk assessment. This survey could constitute a starting point for future investigations on retinal risk, since data on medical monitors emissions and continuative exposure to blue light are lacking. Moreover, a comparison among emission levels of medical and PC monitors - used aside from reporting - was performed to take into account each contribution to the total daily exposure.
Material and methods: The study involves measurements on a sample of medical and PC monitors available at hospital Fondazione IRCCS Policlinico San Matteo, used on a regular basis for reporting in the Radiology Departments.
We used a CCD spectroradiometer to perform a spectral characterization of the monitors wavelength emission, and to make direct measurements of irradiance and indirect calculations of radiance. The chosen method follows international guidelines of ICNIRP and ISO standards.

The obtained values were compared with the Exposure Limit Values (ELV) defined in national and European legislation (Directive 25/2006/UE) regarding blue light emissions.
Results and conclusions: We have characterized the spectral emissions of several medical and PC monitors, and defined a standard method to measure exposure levels to perform a risk assessment conform to European regulations. The values of irradiance and radiance obtained are below the European ELV for acute effects on the eye related to blue light exposure. However, since limit values do not account for continuative exposure, based on the radiance values obtained, observations are made on whether longer exposure times should be evaluated. This will serve as an important starting point for future investigations on retinal risk, most notably for professionals who spend most of their working time in front of a monitor.

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PHYSICS AT THE HEART OF MEDICINE: DEVELOPMENT OF MEDICAL PHYSICS IN THE DUTCH HEALTHCARE SYSTEM 1973-2023

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In the advent of the foundation of the Association for Medical Physics in the Netherlands (1973, NVKF – Nederlandse Vereniging voor Klinische Fysica), an intense collaboration between Dutch physicists working in both university hospitals and general hospitals started in a more formalized way. The Netherlands is a small, densely populated country where distances are short: less than 150 minutes by car to Utrecht in the center from anywhere in the country. This is one of the reasons meetings were, and still are, easily organized.
Five working fields for medical physicists were recognized because (medical} physicists were already active in these working fields. These fields were: radiotherapy, nuclear medicine, radiology, general medical physics and clinical audiology. The exchange of information between MPE professionals during these meetings showed that much could be learned from each other's experiences. It also proved to be profitable to have a worked-out training program for Medical Physics trainees, as there was no such study offered by one of the Dutch universities.
The education and training (E&T) programs for trainees became more and more professionalized and committees were assembled by the NVKF for the creation of curricula for all five working fields of medical physics. The European law on the use of ionizing radiation (96/29/Euratom) formalized the role of the MPE (in Dutch: klinisch fysicus) and the profession was officially mentioned in Dutch Law (BIG, 2005). Around 2008 the E&T programs for MPEs were subsidized by the Government, similar to the support for E&T programs for medical specialists. By that time an independent supervising body was needed. This became the Foundation for Education and Training of MPEs (OKF, Stichting Opleiding Klinische Fysica).
Changes in the way medical specialists were organized in the Netherlands opened the door for associations of non-medical specialists working in hospitals (e.g. clinical chemists, hospital pharmacists, medical physicists) to join the Federation of Medical Specialists (FMS). The NVKF joined the FMS in 2016 and is now a full, well appreciated member of the community of medical specialists in the Netherlands.

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FUTURE TECHNOLOGIES AND PROJECTED INNOVATIONS FOR MEDICAL RADIATION APPLICATIONS AND RADIATION PROTECTION: THE EURAMED ROCC-N-ROLL HORIZON SCANNING SURVEY

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Purpose: To gain insight into what new technologies and projected applications of ionising radiation can be expected over the next decade. This 'stock-taking' exercise builds on a recent Delphi study aimed at identifying key translational challenges for medical ionising radiation and radiation protection research, the results of which, together with the current survey findings, will help to inform the development of a tailored innovation transfer framework for future research in the fields of medical imaging, nuclear medicine, and radiation therapy.
Methods: A cross-sectional online survey targeting professionals involved in ionising radiation-based research and development (R&D), from academia, clinical practice, industry, and regulators, was conducted between November 2021 and February 2022. The survey consisted of 17 open-ended and closed-type questions distributed across three sections which covered demographics, organisation-specific R&D, and the future of medical radiation innovations. Snowball sampling was employed to recruit participants and responses were analysed descriptively.
Results: Fifty-seven individuals accessed the online survey with a completion rate of 67%. There was good representation from academia, research and/or clinical practice (n = 12; 32%), regulation/government (n = 12; 32%), and Industry (n = 14; 37%). Partnerships and collaborative business models were confirmed to be a key component of organisations' R&D strategy by 68% (n = 26) of respondents. Artificial intelligence (AI) solutions (n = 15; 39%) and dose reduction technology and techniques (n = 11; 29%) were the most cited focus areas for organisations' R&D pipelines. Open-ended responses indicated radiopharmaceuticals/radionuclides are also a primary focus. 'Radiotherapy - external beam radiation therapy (EBRT)' (n = 16; 42%) and 'nuclear medicine/radiotherapy – systemic radiation therapy' (n = 14; 37%) are thought to be the overarching fields of medical radiation with the greatest potential for advancement and breakthrough innovation. Additionally, AI solutions are seen as having the greatest potential for breakthrough innovation over the next decade (n = 21; 55%). In terms of anatomical systems, cardiovascular (n = 16; 42%) and neurological (n = 14; 37%) applications of diagnostic and interventional medical imaging are predicted to undergo the greatest advancement over the coming 5-10 years, while applications to the prostate (n = 14; 37%) are seen as having the greatest potential for therapeutic advancement.
Conclusions: A tailored innovation transfer framework for radiological research should be developed with regard for projected innovations, including AI solutions, advancements to EBRT and systemic radiation therapy.

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EURAMED ROCC-N-ROLL: DEVELOPING A EUROPEAN STRATEGIC RESEARCH AGENDA AND A CORRESPONDING ROADMAP FOR MEDICAL APPLICATIONS OF IONIZING RADIATION

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Purpose: Medical applications of ionizing radiation (IR) offer great opportunities for patient diagnosis and treatment. A common approach with synergies from various areas is needed, bringing together the radiation protection perspective and the disease diagnosis and treatment perspective as driven by the health sector for example. Acknowledging the importance of medical applications as the largest man-made source of exposure and the great possibilities of applying IR in medicine, the EURATOM programme has launched a call for a coordination and support action to develop a strategic research agenda (SRA) on medical applications of IR.

Material and methods: As a response, a consortium called "EURAMED rocc-n-roll" of 29 European partners representing a large number of disciplines, has formed to develop such an SRA until Aug. 2023. The major goal is to optimize the use of IR in medicine and thereby improve its benefit to Europe's patients, with a strong focus on the patient perspective and highlighting the potential of individualized radiation-based medicine for combating cancer and other diseases. A European consensus will be generated incorporating research needs, gaps, challenges, opportunities and priorities in the fields in the upcoming decades, via interactive exchanges among industries, suppliers, healthcare professionals, professional and scientific organizations, and regulatory bodies. Therefore, EURAMED rocc-n-roll is conducting a series of survey, literature review, workshops and consultation panels among interested stakeholders, consortium members and external experts.

Results and conclusion: The final outcome will be the documentation of an SRA defining the needs, gaps and opportunities for research, a roadmap highlighting possible priorities in various timelines and predicted necessary budgets and an interlink document representing the interlinks to nearby fields. These documents will serve as decision support for stakeholders, policy makers and funding bodies at EU regarding priorities and needs in this important, interdisciplinary field.

This poster will provide an overview of the activities of EURAMED rocc-n-roll. It will show the current status including the achieved consensus on a structure for the SRA. It will summarize the results of the first (online) workshops and highlight the possibilities to contribute to the documents to be developed, i.e., the SRA, the roadmap and the interlink document.

POSTER ABSTRACTS – RP

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RADIATION DOSIMETRY OF [123I]IMAZA IN PATIENTS WITH ADRENAL TUMORS

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Aim: IMAZA is a newly developed compound. Labelled with I-123, it is a promising diagnostic tracer for the differential diagnosis of adrenal incidentalomas. The aim of this study is to provide data on the biodistribution and dosimetry of [^{123}I]IMAZA.

Method: 131-189 MBq of [^{123}I]IMAZA were administered to 21 patients. After [^{123}I]IMAZA administration, several blood samples were taken between 0.02 h and 24 h. Sequential whole-body planar scans and a single SPECT/CT image were acquired at nominally 0.17, 0.75, 2, 5 (planar + SPECT/CT), 24 h post-injection. Time-activity curves were calculated for the whole-body, the kidneys, the liver and the blood. The whole-body retentions of the patients were derived by normalizing the geometric mean of the net count rates in the planar scans to the first planar scan. The SPECT/CT scan of each patient was used to normalize the planar count rates in the kidneys, the bladder and the liver to the absolute activity concentrations. The blood samples were measured in a calibrated well counter. The time-integrated activity coefficients (TIACs) including uncertainties were calculated by using NUKDOS [1]. The kidney-bladder model with 3.5 h voiding interval was used to estimate the urinary bladder TIACs. The absorbed dose (AD) and effective dose (ED) for each patient were calculated with IDAC-Dose2.1 [2] using ICRP 110 adult computational voxel phantoms.

Results: [^{123}I]IMAZA showed high specific accumulation in adrenocortical tumors in many of the patients; healthy adrenal glands were scintigraphically not visible. Increased activity concentrations were evident in the liver and weakly detectable in the kidneys. Activity excretion was almost exclusively renal; a minor hepatobiliary component was dosimetrically irrelevant. The highest ADs were calculated for the urinary bladder wall (mean ADs per administered activity: 0.06±0.01 mGy/MBq). The mean AD per administered activity values was 0.008±0.004 mGy/MBq for the kidneys and 0.007±0.003 mGy/MBq for the liver. The mean ED was 1.53±0.37 mSv (mean ED per administered activity: 0.009±0.002 mSv/MBq).

Conclusion: The rapid clearance of [^{123}I]IMAZA which resulted in the low background activity improves the diagnostic evaluation at similar or lower doses to organs as compared to [^{18}F]FDG and other ^{123}I- and ^{68}Ga-labeled agents. The individual radiation exposure of [^{123}I]IMAZA is determined largely by the TIAC of the bladder and thus the voiding interval.

References:

[1] Kletting P, et al. Med Phys 2013.
[2] Andersson M, et al. EJNMMI research, 2017.

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ASSESSMENT OF PATIENT RADIATION DOSE FROM RECURRENT CT PROCEDURES IN QATAR

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Purpose: The objective of this study is to evaluate the cumulative radiation exposure of patients underwent to recurrent CT within 3 years period.

Material and methods: Data were selected retrospectively from 19 CTs (10 hospitals) for patients who underwent to CT examination from radiation dose monitoring (RDM) software during the years 2018 to 2020. The effective dose for CT patients was estimated by use dose-length product (DLP) to effective dose conversion factors, called k-factors which may be adopted by most dose monitoring systems Effective dose was evaluated using standard coefficients referring to a generic reference individual. Thus, effective dose (ED) from the CT exam was calculated using the conversion factors k (mSv/mGy cm) multiplied by the DLP.

Results: Data collected retrospectively for a total of 133,994 underwent to CT exams, The average number of exams per patient was1.3.
The highest CED received by single patient underwent to 15 times CT scan was calculated to be 414.4 mSv for 69 years old female patient, the multiple CT scans including, CT head, CT abdomen with contrast, CT abdomen, CT drainage abdomen, CT urinary tract, CT Abdomen KUB, CT abdomen pelvis with contrast.
43%, 11%, 2.3% 0.2%, and 0.04% of patients received ≥ 20 mSv, > 50, ≥100, and ≥300 mSv respectively during the 3 years period.
Over 3-years study period in 133,994 patients underwent CT scans 24,614 (18%) patients exposed to more than one-time procedure. 22 patients (0.1%) underwent to 16-20 exams,95.8% of patients underwent to 2-5 exams. Only 5 patients had more than 20 exams during the specified period. The total number of examinations were 174,940 and the number of exams per patient equal to 1.3 during that period. A total of 564 out of 24,614 (2.3%) of recurrent patients underwent to CT examinations received a CED of ≥100 mSv with mean dose value of 139.5 mSv and maximum of 414.5 mSv.
Conclusion: Although the number of recurrent patients is not high only 2.3% received CED of more than or Equal 100 mSv, dose tracking should be recommender cover governmental and private hospitals to confirm that the cumulative dose is well controlled. Cancer risk assessment should be assessed for the future studies.

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PRECLINICAL DOSIMETRY IN PROTON MINIBEAM RADIATION THERAPY: ROBUSTNESS ANALYSIS AND GUIDELINES

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Purpose: Proton minibeam radiation therapy (pMBRT) is a new radiotherapy approach (Prezado, 2013) that has shown a significant increase of the therapeutic window in glioma-bearing rats, as compared to conventional proton therapy (Prezado, 2018). These results have raised an interest to initiate pre-clinical investigations at several centres worldwide The dosimetry in pMBRT is challenging and error-prone due to the submillimetric beamlet sizes used. The aim of this study was to perform a robustness analysis on the setup parameters utilized in current pre-clinical trials and provide guidelines for a reproducible dosimetry. Results of this work are intended to guide upcoming implementations of pMBRT.
Materials and methods: Monte Carlo simulations and experimental data were used to quantify the uncertainties on lateral pMBRT dose distributions related to possible variations in collimator characteristics (e.g., posititioning, with and divergence of the slits, etc) and setup parameters. The value of each parameter was modified individually to evaluate their effect on dose distributions. Experimental dosimetry was performed by means of high-resolution detectors, i.e., radiochromic films, the IBA Razor and the microdiamond detector. A new methodology, based on the alignment of the beam with the collimator, was proposed to optimize the experimental setup in pMBRT studies.
Results: Quantities that define pMBRT lateral profiles (i.e., the peak-to-valley dose ratio, peak and valley doses, and peak width) are significantly influenced by small-scale fluctuations in several of those parameters. Accordingly, the setup implemented in the Orsay proton therapy centre was optimized following the methodology proposed. Guidelines for a robust dosimetry were also proposed and followed to perform accurate and reproducible dosimetry for pre-clinical trials.
Conclusions: This study revealed the importance of adopting protocols tailored to the distinct dose delivery method and dose distributions in pMBRT. This new methodology leads to a reproducible dosimetry, imperative in pre-clinical trials. The results and guidelines presented in this work can facilitate the initiation of pMBRT investigations in other centres.

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DOSE OPTIMIZATION FOR 68GA DOTA-TOC PET USING MACHINE LEARNING ALGORITHMS

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Purpose: ^{68}Ga-DOTA-TOC PET/CT scans are an essential tool in serial monitoring and therapy selection for patients with Neuroendocrine tumours. The amount of gallium obtained per elution decreases significantly as the ^{68}Ge/^{68}Ga generator ages, resulting in decreasing number of patient doses available. Reducing the amount of gallium administered to the patient would increase the number of patient doses available per elution, while also reducing the radiation dose to the patient. However, reducing the administered activity will have an impact on the qualitative and quantitative imaging parameters of the PET/CT scan. The aim of this study was to identify the minimum administered activity of ^{68}Ga-DOTA-TOC that would still provide adequate clinical information.
Material and methods: 10 ^{68}Ga-DOTA-TOC PET/CT patient images acquired on a Siemens Biograph Horizon PET/CT scanner were iteratively reconstructed to simulate reduced activity images, with reconstructions ranging from 100% to 10% activity-equivalents. For each reconstruction clinical image quality was visually assessed by a Radiologist and scored using a 4-point Likert scale. Over 150 quantitative metrics were also measured for each reconstruction, including count-based metrics, SUV-based metrics and radiomic feature extraction. A machine learning algorithm, Random Forest Classification(RFC), was implemented to identify the key metrics that most accurately predict the Likert score, enabling a larger number of additional patient scans to be analysed and deemed clinically acceptable or not, without the need for clinical review.
Results: The results of the 10-patient study found that the activity of ^{68}Ga-DOTA-TOC may be reduced by up to 50% without the loss of clinically relevant information. 5 key metrics were identified that could predict the Likert score with an accuracy of 97% (pNEC, Liver and Spleen standard deviation, Spleen SNR and lesion CNR). A further 30 patient scans were then reconstructed with a 50% activity-equivalence and analysed to assess the change in quantitative metrics. All scans were found to be clinically acceptable. The lesion SUV metrics did not undergo a statistically significant change. While some SUV metrics of homogenous organs such as the liver and spleen were significantly impacted by the reduction in counts, the most stable background metrics for serial monitoring have been identified.
Conclusion: RFC has proved to be a useful tool in dose optimization. The results obtained to date suggest that the administered activity may be reduced by up to 50% without a loss of clinically relevant information. Additional patient scans are currently being analysed and their results will also be presented.

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PREDICTING AND CONFIRMING THE LINAC TARGET DEGRADATION

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Purpose: The calibration procedures of the photon beams performed according to the report IAEA TRS 398 are claimed by Varian to be a potential cause of burning out the medical accelerator target material. In order to detect the first symptoms of the target degradation, specialized software monitoring its state in real-time was installed at the linac's consoles by the vendor. The warnings and the interlocks generated by the program encouraged us to perform the advanced dosimetric analysis of the photon beam to find the parameter indicating the target degradation most accurately and before its complete damage.

Material and methods: The basic physical parameters characterizing the 6 MV photon beam with a flattening filter of three Clinac 23Ex were analyzed. The vendor's program repeatedly generated warnings of the target degradation for each of them. The variability of the profile shape, the beam quality index and the dose output measured in a water phantom were analyzed. The beam profile measurements were performed at the depth of the maximum dose and compared with the data collected during the accelerator commissioning. To identify the differences in the profile shape at the edge of the beam the field size of 30 cm × 30 cm was chosen.

Results: The target degradation was not confirmed by the two non-invasive tests suggested by the vendor. The analysis of the 6 MV photon beam parameters under the reference conditions in water indicated that only for one Clinac 23Ex an increase in the beam homogeneity of approximately 1.5% took place, but it corresponded to a QI change of 0.5% as compared to the value obtained in the measurements for the treatment planning system. The effect of the beam softening is the most visible at the depth of maximum dose and the largest field size, where the profile arms are lowered near the edge of the radiation field. In none of the cases, the dose rate reduction reached the values given in the manufacturer's technical note. The advanced degradation of the target was also visually confirmed. Thus, the program was revealed to be a sensitive, but not very specific tool.

Conclusions: Due to a mentioned non-specificity of the target testing tool, an additional protocol to control the profile shape stability for the 6 MV photon beams at the depth of maximum dose in the field 30 cm × 30 cm was introduced in MSCNRIO.

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INFLUENCE OF X-RAY SPECTRA AND BOWTIE FILTER MODELLING ON SIMULATED CT ORGAN DOSES

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Purpose: As part of the EU Horizon 2020 MEDIRAD project, patient-specific CT dosimetry was performed through Monte Carlo simulation. To obtain the best results, quantitative spectral information and information on the bowtie filter material and shape need to be provided by the manufacturer. However, manufacturer's data are not always available. In this study, the influence of different X-ray spectrum determination and shaped filter modelling methods on simulated CT organ doses is studied.

Material and methods: Monte Carlo dose simulations were performed with ImpactMC for twenty adult patients undergoing a diagnostic CT scan at 120 kV with tube current modulation as part of a whole-body PET/CT examination on a Siemens Biograph mCT Flow. First, the X-ray spectrum and bowtie filter model provided by the manufacturer were used as input for the simulations. Next, X-ray spectra created with the integrated ImpactMC and SpekCalc spectrum generator and based on half-value layer measurements combined with the SPEKTR tool applying a voltage ripple of 0% and 25% were used for the calculations. Finally, the bowtie filter model based on measured dose value was applied in combination with each X-ray spectrum.

Results: For all X-ray spectrum and bowtie filter combinations, estimated CT organ doses are within 6% from those resulting from simulations with the spectrum and bowtie filter model provided by the manufacturer. While varying the bowtie filter model results in CT organ dose differences smaller than 1%, the X-ray spectrum has a larger influence. Irrespective from the used bowtie model, dose differences up to 6% are observed when X-ray spectra are not based on the quantitative data from the manufacturer. Disregarding all situations using quantitative manufacturer's data, the best results are obtained by determining equivalent energy spectra with a voltage ripple of 0% based on half-value layer measurements combined with the SPEKTR tool and model the bowtie filter based on dose measurements. Organ dose differences are then within 3%.

Conclusions: When manufacturer's data are not available, half-value layer and dose measurements, which can be performed without special equipment, provide sufficient input to obtain equivalent X-ray spectra and bowtie filter profiles, respectively. Monte Carlo simulations then result in estimated CT organ doses that deviate less than 6% from the most accurate simulations.

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ACTIVATION OF BOLUS IN PROTONTHERAPY TREATMENTS

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Purpose: Boluses in protontherapy are usually employed for superficial tumours that frequently show a non-conformal anatomy. In our hospital, we develop patient-specific bolus in order to provide superior setup robustness, dose uniformity and conformity. They cover usually 4 to 5 cm depth (not achievable with available proton energies at our institution, Hitachi ProBeat-CR) and have proved to behave pretty similar to patient tissue (ρ=1.18g/cc). This implies that they may also suffer from nuclei activation. Nevertheless, there is little knowledge about this activation in clinical protontherapy and its impact in terms of radiological protection. In this work we aimed to study activation and dose rates that may affect protontherapy staff and patients as a consequence of the treatments.

Material and methods: For our purpose, we chose 2 patients, having different boluses (foot melanoma and lacrimal) and measured in contact just after treatment irradiation (lacrimal: 2beams x36 MU, 77-146 MeV: range 15 cm, SOBP:9.5 cm and Φ=11 cm; feet melanoma: 1beam x428 MU, 70-130 MeV: range 12 cm, SOBP:8.2 cm and Φ=26.7 cm), both of them with a 4 cm bolus.

We performed several dose rate measurements in terms of H*(10) in patient and bolus surfaces, a short period after irradiation (from the

end until 20' later) in order to assess decay rates in clinical treatment conditions. We evaluated as well activation spectra for short term measurements besides a long-term one, in order to assess for all the possible active nuclides in the bolus. We used a MiniTRACE™ (Saphymo) multipurpose meter for dose rate measurements and a RIIDEye-M-G (Thermo Scientific) spectrometer to identify the radionuclides.
Results: Dose rates measured for just at the end of the irradiation were of 55 and 120 µSv/h for the lacrimal and foot boluses and 17.5 and 15 µSv/h for each patient, respectively, decreasing. Bolus dose rates decreased to tenth of its initial value after 40'. Regarding nuclei activation, three different decay curves were found for patient and bolus (2, 9.9 and 20.3 min, associated to 15O, 13N and 11C regarding their half-life values) for the short-term spectra and long-term measurements performed in the bolus (24h after irradiation) showed an additional peak (479 keV) due to 7Be.
Conclusions: Personalized bolus and patient activation after clinical irradiations was evaluated, showing the presence of 11C, 13N, 15O and 7Be. Further measurements using different materials and irradiation conditions are planned in order to better assess activation in protontherapy facilities.

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DEVELOPMENT OF A METHOD TO ESTIMATE OPERATOR'S EQUIVALENT HAND DOSE DURING CT-GUIDED LUNG BIOPSIES

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Purpose: The aim of this study was to develop a method to estimate the equivalent dose to operator's hands during CT-guided lung biopsies for prior risk assessments. The focus of this study was lung biopsies due to the increased use of this procedure in recent years and its high dose nature.
Materials and methods: The CT scanner used was Siemens SOMATOM Emotion 16 which has a dose saving system called HandCARE. HandCARE turns off the beam for a 100° angle in a position selected by the user, preventing exposure to the unattenuated primary beam. A phantom study was carried out using a CTDI body phantom, radiation output detector (RaySafe X2), CT pencil ionisation chamber and survey meter. The operator's hand in-beam and at approximately 40 cm while the beam was on were observed to be the most used positions. The time and dose rate at these positions were measured in the phantom study. The measurements were used to determine the equivalent dose per procedure. A clinical study was used to validate the results of the phantom study. The operators wore a ring dosimeter (from an approved dosimetry service) on each hand during all CT-guided procedures for five weeks.
Results: The dose rate measured in the beam was 0.11 mSv/s and at 40 cm was 0.0074 mSv/s. The operator's hand was in the beam for an average of 36 s/procedure and the operator's hand was observed to be at 40 cm for an average of 58 s/procedure. The dose per procedure for lung biopsies was determined to be 4.3 mSv/procedure from the phantom study. The average dose per CT-guided procedure determined from the clinical study was 3.1 mSv/procedure.
Conclusion: The dosimeters were worn for lower dose CT-guided procedures in addition to lung biopsies. This reduced the average dose per procedure and contributed to the difference between the phantom and clinical results. While the results shown here are specific to this CT system and the dose saving method used, the methodology presented can be used to determine equivalent dose to the operator's hands. This information may be used to assist in the categorisation of workers for local risk assessments.

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CHEST CT PRACTICES EVOLUTION DURING COVID-19 PANDEMIA IN FRANCE

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Purpose: Computed tomography (CT) has been considered as a reference for the diagnostic screening of patients suspected of COVID-19. Learned societies produce guidelines in terms of image quality and patient dosimetry. We conducted a multicenter study in France to determine the impact of the recommendations on chest CT practices and effective dose.
Methods: We analyzed structured reports automatically transmitted by 35 centers to our dose archive communication system ALARADose. Technical parameters of acquisition, as well as dosimetric indices and frequency were studied between the beginning of 2019 and October 2021.
Results: The COVID-19 pandemic has greatly increased the use of thoracic CT in France (+20%). The analysis of technical and dosimetric parameters shows that the low dose recommendations were not applied (< 5%) but levels remain below the official Diagnostic Reference Levels (DRL). The number of examens are correlated with the availability of PCR tests and French hospitalization data. During the arrival of the different waves of contamination, the chest CT is replaced as reference by PCR tests.
The impact of x-rays on the future health of the patient remains to be assessed. Given the radiosensitivity associated with the thorax and the increase in procedures during the first waves of contamination implies an increase in effective dose for this group of patients.
Conclusions: Chest CT was very useful and largely used during COVID-19 pandemic. Recommendations for chest CT scans in suspected or confirmed COVID-19 patients were not followed, with less than 5% of low-dose procedures performed in the 30 centers analyzed. Vaccination seems to have had a great impact on CT workflow before the third outbreak. However, chest CT dose optimization has to be improved.

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FACTORS INFLUENCING THE ACCURACY OF RADIATION DOSE ESTIMATION IN THE C-14 UREA BREATH TEST

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Purpose: Limitations of structure reduction of the mathematical models applied for dose estimation purposes should be well-defined. The aim of the study was comparison of radiation dose estimation for the C-14 labeled urea breath test based on 3 different simplified models and for different input parameters.
Material and methods: One-compartment model, two one-compartment sub-models and a three-compartment model of C-14 urea kinetics in organism (for absence and lack of H.pylori infection) were tested. Calculations were done for the basic and modified literature fractional transfer rate constants between the body and the environment to check the models sensitivity, additionally. The dose for the total body was estimated as the product of the adequate in each case cumulated activity and the S factor presented in: MIRD Pamphlet No. 11: S, Absorbed Dose per Unit Cumulated Activity for Selected Radionuclides and Organs for C-14.
Results: The results showed underestimation of the dose in comparison to the reference model consisted of two submodels:

a gastric urea absorption/distribution/excretion model and an adaption of the three-compartmental model of high, low blood flow tissues and "relatively fixed" group of tissues developed following ICRP recommendations. Simplified models caused an order of magnitude difference to originally calculated doses (several μSv), even for modified input parameters.

Conclusions: The dose of C-14 labeled urea during the urea breath test should be estimated by the complex models or new set of fractional transfer rate constant based on the experiment should be applied for the less complex mathematical models. Although the radioactivity delivered during urea breath test is low, the radiation dose may be clinically significant if the test is repeated frequently to monitor the treatment effects or the patient has kidney problems.

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WIRELESS DOSIMETRY FOR INTERVENTIONAL RADIOLOGY OPERATORS

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The need for real-time measurement of personnel exposure during interventional radiology procedures is growing. The dosimetry is typically performed using passive dosimeters. Only some real-time educational devices are currently available. In this work, we will present the RAPID wireless dosimeter, its calibration in certified radiation fields, the characterization with phantoms in a clinical environment and some results when worn during clinical procedures by the operators.

The measurement fredquency is 5 Hz, and the device is operated on batteries, with more than 8 hours duration and 4000 recharge cycles.

The precision of the measurement lies between 5-10% for all typical exposure to X radiation scattered by the patient's body.

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TOOLKIT FOR CHARACTERIZING THE RELEVANT PARAMETERS OF A NOVEL UHDR LINAC FOR PRECLINICAL FLASH-RT

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FLASH radiotherapy (RT) uses ultra-high dose rates (UHDR, >40 Gy/s) over a very short time (<100 ms) and shows to maintain an anti-tumoral effect with less normal tissue toxicity. Acceptance procedures for UHDR systems are not standard and dosimetry is challenging. Common real-time detectors such as ion chambers and semiconductors present saturation behaviour at high dose per pulse due to recombination issues and fail to accurately measure dose (Di Martino F., Front. Phys. 2020). Passive detectors such as alanine, Gafchromic films, and TLDs are currently considered the best candidates for absolute dosimetry. We present a protocol for system commissioning using clinically available dosimeters, optimizing the use of the detectors.

Measurements were performed on a dedicated research electron linac for FLASH-RT (ElectronFlash, SIT, Italy) at 7 and 9 MeV in fields of 40, 100 (reference), and 120 mm in diameter. The system is highly tunable for pulse length, pulse repetition frequency and number of pulses. The dose rate ranging from 0.044 to 2.2 Gy/s in reference conditions. The dose per pulse (DPP) was varied using pulse length, distance from the linac and e-gun current. We used standard detectors: a PTW Advanced Markus (AM) plane-parallel ion chamber, Gafchromic EBT-XD films, and alanine pellets. Measurements were performed in an adapted PTW MP3 water phantom and in solid water (RW3). Stray radiation was monitored using Fluke 451 B and Camberra Babyline 81 survey meters.

Performance tests assessing dose, dose stability, PDD, profiles, and output linearity to system settings were measured cross-referencing at least two detectors (agreement within 5%). Energy and dose output, monitored with films and AM, were stable within 5% in several months. Periodic checks are needed. The AM was employed for daily QA for doses up to 0.5 Gy/pulse using a modified model from Di Martino et al, Med. Phys. 2005. The measured doses show a good agreement (2% against film) up to 0.8 Gy/pulse. Varying the DPP resulted in a linear output change and minimal spectral variation (<1 MeV) for all three parameters. Stray radiation never exceeded 2.5 10^{-5} Sv/MU at 1 m from a RW3 phantom.

We characterized the ELF using a standard toolkit, combining alanine and Gafchromic films as absolute dosimetric standards. The AM can be employed as real-time tool for daily QA.

This work is part of the 18HLT04 UHDpulse project which received funding from the EMPIR programme.

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DESIGNING AN ULTRA-THIN PARALLEL-PLATE IONIZATION CHAMBER FOR ULTRA-HIGH DOSE RATE APPLICATIONS

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Purpose: Air-vented ionization chambers (IC) are the most used secondary standard of absorbed dose to water. In conventional beams (dose per pulse up to few mGy) commercially available ICs can be used thanks to relative small recombination losses. This is not the case in ultra-high dose rate (UHDR) regime where the traditional IC exhibit poor collection efficiency due to ion recombination.

Material and methods: A detailed simulation of the charge carrier transport was developed to understand the behavior of the ionization chambers beyond the conventional regime. Based on the results of the simulation it is concluded that the electrode distance is the parameter with the most impact in the collection efficiency. This is mainly due to three factors: reduced charge collection time, increase of the electric field and resulting increased the free electron fraction. A distance between electrodes of 0.25 mm is estimated to be suitable to measure up to 7.5 Gy per pulse (pulse duration of 2.5 μs) at 300 V operating voltage with recombination losses lower than 1%.

Two air-vented so-called ultra-thin parallel-plate ionization chamber (UTPPIC) where assembled in the University of Santiago de Compostela. The two prototypes were tested at SIT (Aprilia, Italy) and at Physikalisch-Technische Bundesanstalt (PTB, Bundesanstalt, Germany).

Results: The prototype tested at PTB showed a deviation from linearity lower than 2% up to 5.4 Gy per pulse and pulse duration of 2.5 µs at 250 V operating voltage. The prototype tested at SIT (Aprilia) has shown no significant recombination effects up to 10 Gy per pulse, 4.5 µs, operated at 300 V.

In contrast to the conventional regime the effective free electron fraction in IC under UHDR depends on the dose per pulse and is not a constant determined by geometry and operating voltage.

Conclusions: The UTPPIC can be used for dosimetry in UHDR electron beams. As the ion collection time is of the same order of magnitude as the pulse duration the Boag-like formalism cannot be used because collection efficiency is function of the pulse duration. The reduction of the chamber electrode distance has its limitations. At smaller electrode distances (<0.25 mm), undesired phenomena such as two-body attachment and electron multiplication are expected to be significant.

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NEUTRON DOSE EQUIVALENT INCREASE DUE TO RANGE SHIFTER IN ACTIVE PROTON THERAPY

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Purpose: Targets located superficially in the body often require a range shifter (RS) when treated with protons to bring the energies in the necessary energy range. The addition of this beamline element increases the neutron production during irradiation which may be a concern in some cases. The aim of the present work is to estimate the increase of neutron dose equivalent in the patient when using the RS. Clinically-relevant positions of the RS were considered.

Material and methods: A simple geometry was used for Monte Carlo simulations using the MCNP 6.2 code. A SOBP was created to cover a target volume of 15x10x4 cm^3 at a depth of 4 cm inside a water phantom. This field was considered to mimic a typical field for Hodgkin's lymphoma patients. The RS (Lexan, 3.5 cm thickness) was placed between two positions representing the maximum and a typical airgap to the patient surface: 17.4 cm (RS1) and 29.9 cm (RS2). The configuration with no RS was also considered for reference. Neutron spectrum and dose equivalent were evaluated in selected points around the target at distances from 0.5 up to 60 cm from field edge.

Results: Neutron spectra showed in each position almost no differences between the 3 configurations. The main dose contribution comes from fast neutrons, up to 50% in the positions closer to the target and continuously reducing when going farther from the target. In terms of dose equivalent, RS configurations led to higher values, especially with the RS closer to the tank surface (RS1). For positions located laterally to target (at isocenter depth), the increase was of 17% and 11% at 5 mm from field edge for RS1 and RS2, respectively. These values were continuously increasing as moving farther from the target: 56% and 38% at 5.5 cm and 107% and 76% at 9.5 cm for RS1 and RS2, respectively.

Conclusion: An estimation of the increase in neutron dose equivalent when using RS has been performed. For the simple geometry considered with no other nozzle elements simulated, the results represent the contribution of internal neutrons together with the contribution of the material of RS itself. It is however expected that the inclusion of other elements would lead to comparable effects for all configurations.

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EXCESSIVE TUBE LEAKAGE OR EXCESSIVE CAUTION

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Appropriate radiation shielding of an x-ray tube is essential for the radiation safety of patients, members of the public and staff in the hospital. Leakage radiation is considerably harder than primary beam radiation as it passes through lead and must be within regulatory limits. This is particularly important for mobile units used outside the imaging department, where the operator will not have an enclosed shielded area to stand behind.

To ensure that an appropriate level of shielding is installed during the manufacturing process, medical physics carry out an assessment radiation leakage. This assessment is to ensure compliance with international standards (RP162, IEC 60601-1-3:2008) prior to clinical use.

During a recent commissioning of a new mobile x-ray unit the measured radiation leakage was in excess of 10 times higher than normally observed and approaching the 1 mGy h-1 limit. It is important to note that duty cycle adjustments will bring this level down for the manufacturer in question. This experience instigated a comprehensive review of the scientific techniques for assessing leakage on a range of systems across two hospital groups. Dose rate and dose per exposure were noted at the maximum rating and at a fixed level for direct comparison between systems. The tube shielding specifications provided by the different manufacturers was also reviewed.

Confidence in evaluation methods for assessment of tube shielding is crucial for physics commissioning of an x-ray system. Inappropriately shielded tubes present a radiation risk to members of the public and staff and potential degradation of the patient's image.

There are also implications for use of mobile x-ray systems where excessive tube leakage is present, which will include additional radiation control measures. The manufacturers of these systems have a responsibility, which is beyond meeting the minimum IEC standards, to optimise radiation protection based on the ALARA principle.

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STOCHASTIC EFFECTS IN IODINE THERAPY

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Introduction: The main focus on the effects of radiation dose in iodine therapy is on deterministic effects, both from the point of view of delivering the intended therapeutic dose to the target organ/ cells, and on limits to the 131I activity that may need to be considered to avoid deterministic effects to non-target organs or cells, especially for repeat cancer therapies. However, the radiation exposure to non-target tissue and organs, and to surviving thyroid tissues, may still result in harm and have the potential to cause stochastic effects. This papers focuses on the potential for stochastic effects and on how these risks are understood by clinicians and communicated to patients.

Methods: The scientific literature on the potential for secondary cancers from radioiodine therapies is reviewed. Iodine therapy for both hyperthyroidism and ablation are included. Different methods in which risk is assessed are considered. Finally we look at how stochastic risk is interpreted in the clinical literature and how this risk is explained to patients both in the guidelines for iodine therapy, and in the standard advice available on-line.
Results and discussion: A summary of the current literature reporting risks of secondary malignancy following radioiodine therapy are presented. Data from different methods to assess risk are reviewed (e.g.- organ dose; effective dose; epidemiological studies; etc.). Differences in cancer risk following ablation therapy and hyperthyroidism treatments are also presented. Statements about stochastic risk in the clinical literature are then examined. We contrast the interpretation and communication of stochastic risk in radioiodine therapy with the interpretation and communication of similar risks in diagnostic exams.
Conclusion: We review interpretation of risk of stochastic effects following radioiodine therapy and suggest ways in which communication of these risks might be improved.

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SURGEON EYE LENS AND WHOLE BODY EFFECTIVE DOSE CORRELATION IN INTERVENTIONAL PROCEDURES: A MULTI-PROCEDURE STUDY

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Purpose: Reduction of the recommended equivalent dose limit for the lens of the eye from 150 mSv/year (ICRP, 2007) to 20 mSv/year averaged over five years and with no year exceeding 50 mSv, may require an accurate eye lens dose monitoring to be performed in interventional procedures, especially for surgeons. A dedicated dosemeter close to eye lens may help but at the same time introduces operational complexity.
The purpose of this study is to assess the correlation between the Hp(3) dose measured close to the eye lens and the Hp(10) whole body effective dose measured over the surgeon's lead apron.
Material and methods: Eye lens dose was measured with a TLD dosimeters calibrated in terms of Hp(3) placed close to surgeon's most exposed eye. Whole-body dose Hp(10) was measured with TLD card located on the external lead apron.
Surgeon doses were measured in selected significant, with respect to radiation protection, interventional procedure in a multi-centre survey: coronary angiography and percutaneous transluminal coronary angioplasty, arteriovenous malformations and aneurysms embolization, endovascular aortic repair, peace-maker implantation, and ct-guided biopsy. The literature about the latter is scarce.
Results: A statistically significant correlation between Hp(10) and Hp(3) for the same surgeon and the same procedure was found.
No correlation was found within procedures, with Hp(3)/Hp(10) ratio varying in the range 0.3-1.0 ; this is due to the large variability of monitoring conditions, including X-ray tube position, relative position of the two dosimeters, the difference in height between surgeons, the surgeon position with respect to scatteting source, the shield used.
Conclusions: a correlation study comparing the eye lens dose and the personal effective dose could provide reference values and variability ranges to be used for eye lens dose evaluation. A large variability depending on surgeon exposure factors and procedure type was found.

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OCCUPATIONAL DOSES IN INTERVENTIONAL ANGIOGRAPHY AFTER RADIOLOGICAL PROTECTION TRAINING AND USE OF A REAL-TIME DIRECT DISPLAY DOSIMETER

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Vascular x-ray guided interventions are complex and may result in high occupational doses to ionising radiation if staff do not take appropriate actions to minimise their exposure. In this prospective intervention study, ten staff members wore an extra personal dosimeter on the upper body above their regular protective clothing during four subsequent periods. Between each period either additional practical radiological protection training was given or a real-time direct display dosimeter were provided to the staff. Each staff's personal dose equivalent, Hp(10) normalised to the total air kerma-area product for the procedures where each staff were involved, KAPt, was used as the dependent variable. Focus-group interviews with the staff were performed with regards to the usefulness of the training and real-time dose rate display system. Our aim was to investigate if the interventions (practical training or real-time dose rate display) did affect the staff doses in the short and long time perspective (5 month later) scale. Significant ($p<0.05$) reductions of staff doses Hp(10)/KAPt after training and use of real-time dose rate display were found and was maintained after five month without additional intervention. Result from the focus-group interview indicated that making radiation "visible", during practical training and usage of real-time direct display dosimeter, eased understanding about how to act for lowering occupational doses.

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EFFECT OF MOBILE PHONE GLASS BACKGROUND ON RETROSPECTIVE DOSE ASSESSMENT

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Purpose: In addition to the intrinsic zero dose signal of unirradiated (unused) mobile phone glass aliquots that is well-described in the literature, the constant background may also have a significant impact on the estimation of lower retrospective doses. The purpose of this study was to evaluate the thermoluminescence background signal from the iPhone 6 display glass depending on the dose, time schedule and readout mode.
Material and methods: Samples were taken from the lower (22 aliquots, group I) and side (24 aliquots, group II) parts of the iPhone 6 display. Half of group I samples were irradiated (1 mGy and 39 mGy) and the other half were left unexposed. In group II material background measurements were always performed after dose readout (0.3-0.4 Gy): two times directly after the measurement and three times 7 days after readout. Two modes of readout were applied: READER (50°C/3 s, 400°C/10 s and 400°C/10 s) and ANALYSER (2°C/s up to 400°C).

Results: The signal from unexposed samples was 80% and 88% of the irradiated samples signal in the READER mode, 55% and 60% in the ANALYSER mode in group I for 1 mGy and 39 mGy, respectively. In group II, the value of the second background measurement was on average 5 times lower than in the case of the first measurement in the READER mode, whereas subsequent background measurements did not change in the ANALYSER mode. The mean background values measured in group II immediately after dose readout and a week later were on a similar level. The results of the third measurement did not differ from the second.
The background of analysed aliquots was on average 5-10 times lower than their initial zero dose signal and these two parameters cannot be confused.
Conclusions: The study showed that the thermoluminescence background signal of glass from mobile phone displays may contribute significantly to the estimated low doses. Changes in readouts for the following background measurements depend on the selected mode.
From a practical point of view, the procedure of subtracting the background signal after each sample readout would be the most advantageous and would make it possible to obtain accurate results, especially when it comes to low doses, as the contribution of the background signal to the final result is much higher than in the case of high doses.

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THE RADIATION PROTECTION OF SPEECH AND LANGUAGE THERAPISTS. SHOULD WE BE CONCERNED?

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Purpose: Video fluoroscopy swallow studies undertaken by Speech and Language Therapists (SLTs) are very common in Ireland. There is little data in the literature with regards to the annual radiation doses received by SLTs during these procedures and whether they should be designated as exposed workers. The level of formal training in radiation protection that is currently received or that may be required by SLTs in Ireland is also unknown.
Materials and methods: An anthropomorphic chest phantom attached to a 16cm perspex cylinder was used to simulate a patient. Scatter radiation was measured with a calibrated survey meter using the local clinical protocol and setup at three hospitals in the Dublin Midlands Hospital Group in Ireland. The Dose Area Product (DAP), annual workloads, SLT PPE and staff positions in each room were also recorded. The current level of formal radiation protection training, as well as an assessment of training requirements required by radiation protection regulations, were also assessed.
Results: The annual radiation doses were calculated using the scatter data, workloads and DAP to be 124μSv, 2μSv and < 1μSv across the three hospitals. This indicates that it is very unlikely that there will be a requirement to designate SLTs as exposed workers provided that adequate PPE is provided. It was noted, however, that SLTs in Ireland do not receive any formal undergraduate or postgraduate training in radiation protection. Some level of ad hoc training is provided locally but this is usually generic in nature or designed for other staff groups. A 2hr RP175 based online radiation protection course designed specifically for SLTs was developed by the Medical Physics Dept. in St James's Hospital and focused on key areas such as basic radiation physics, the biological effects of radiation, the importance of QA/QC, regulations and clinical audit as well as practical radiation protection such as ALARA, time distance and shielding, tube placement, patient positioning, PPE and patient communication. At the end of the course, attendees complete a short exam before receiving their certification of completion.
Conclusions: While it is unlikely that SLTs working in Irish hospitals will be required to be designated as exposed workers, it is important that adequate training, tailored to the specific needs of SLTs performing video fluoroscopy swallow studies, is provided. To meet this need, a flexible, online radiation protection course designed especially for SLTs to ensure best radiation practice was developed.

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MAILED DOSIMETRY AUDIT OF ACTIVE SCANNING PROTON BEAMS IN TEN PROTON THERAPY CENTERS

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Purpose: The goal of the study was to prepare and realize a mailed dosimetry audit of proton therapy centers equipped with spot scanning treatment units.
Material and methods: An assembly for passive detectors positioning in a water phantom was developed and tested in a pilot experiment in CCB IFJ PAN (Poland) and PTC (Czech Republic) in June 2020. In 2021, in the frame of INSPIRE project joint research activity, audit manuals, detectors and holders were distributed to the participating centers. Alanine, radiophotoluminescent and thermoluminescent detectors from seven dosimetry laboratories were used. Detectors were calibrated in Co-60, and an additional LET correction was not applied. The audit consisted of dose determination for two plans: a single 170 MeV scanned 10×10 cm^2 field (Plan P) and a homogeneous 10×10×10 cm^3 target volume (Plan S). The effective point of detectors was placed at the isocentre at 2 and 15 cm for Plan P and Plan S, respectively. Absorbed dose was verified using an ionization chamber and plan rescaling to deliver prescribed dose (2 or 15 Gy) was allowed.
Results: Ten European proton therapy centers participated in the mailed dosimetry audit. Preliminary results indicate a good dosimetric agreement between participating centers. The response of alanine detectors falls within +/-1.7% and +/-2.7% of the average value for plan P and plan S, respectively. Results for TLDs are within

+/-2.0% and +/-4.4% of the average value for plan P and plan S, accordingly.
Conclusions: After a successful initial experience, mailed audit of scanning proton beams may become a part of clinical routine helping in standardization of proton beam dosimetry.

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INVESTIGATING THE PERFORMANCE OF INORGANIC SCINTILLATION DETECTORS IN KILOVOLTAGE AND MEGAVOLTAGE X-RAY BEAMS USING A NOVEL SCINTILLATION DOSIMETRY PLATFORM
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Scintillation detectors are proving to be a viable solution in pre-clinical and clinical dosimetry. They offer several advantages over conventional dosimeters including small geometries, real-time readout, in-vivo capabilities, immune to magnetic fields and water equivalence in the case of plastic scintillation detectors (PSDs). Several groups are developing scintillation dosimetry solutions for both research and clinical applications. Inorganic and organic scintillator detectors have been developed and each can have advantages over the other depending on the chosen scintillator. The purpose of this study was to investigate the performance of novel inorganic scintillation detectors (ISDs) and benchmark their performance against organic scintillation detectors and commercial dosimeters.
To evaluate the potential for ISDs in applications from radiology to radiotherapy it is important to characterise the detectors in kilovoltage and megavoltage beams. In this study, kilovoltage measurements were conducted using the Ziehm Solo C-arm and a radiotherapy linear accelerator for megavoltage measurements. A variety of ISDs have been developed in-house with varying geometries and scintillators (including Gd2O2S:Tb, Gd2O2S:Eu, Gd2O2S:Pr and ZnS:Ag) to optimise the ISD depending on the application. A novel four detector probe module has been designed to allow for simultaneous ISD and PSD readout via the HYPERSCINT research platform (RP-200). The HYPERSCINT system is capable of hyperspectral dosimetry measurements allowing for removal of background and stem signals.
The evaluation included investigating a range of standard parameters such as varying field size, dose, depth dose, dose rate, temperature, energy and radiation angle. Small standard deviations are required in the measurements to ensure measurements are repeatable and reproducible. For example, with a 6 MV photon beam the ISD system demonstrated very good repeatability and reproducibility of the output signal with only a maximum of 0.17% and 1.00% differences from the average values, respectively. The results also showed excellent linearity of the output signal with radiation doses from 50 cGy up to 500 cGy (R2 = 0.999999), and the detector response was independent of dose rate. In the kilovoltage energy range the ISD measurements again displayed excellent linearity however depending on the scintillator used the standard deviation in the repeatability (0.38% - 2.64%) and reproducibility (0.8% - 10.9%) varied significantly. Detailed results will be presented on these key parameters which are critical in clinical dosimetry applications including their variation as a function of kilovoltage to megavoltage energy range.

POSTER ABSTRACTS – RT

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TWIN-BEAM DUAL-ENERGY CT FOR DOSE CALCULATION AND IMAGE GUIDANCE IN RADIOTHERAPY
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Purpose: Dual-energy CT (DE-CT) is a promising technology which has recently become available on commercial CT scanners. In addition to standard single-energy CT (SE-CT), DE-CT can provide high- (H) and low- (L) energy CT scans for an image-based generation of virtual monoenergetic (VMI) and electron density (rho) images. These can potentially improve delineation but should, however, not compromise treatment quality in other steps of radiotherapy (RT) chain. Currently, limited guidelines exist using DE-CT in RT. In this study, we investigate DE-CT reconstructions for dose calculations and image guidance in RT (IGRT).
Material and methods: A cylindrical plastic phantom (Cirs Inc.) with tissue-equivalent inserts of know mass density (MD), relative electron density (RED) and stopping-power ratio (SPR), and, an anthropomorphic head-and-neck (HN) phantom (Max-HD™, IMT Inc.) were subject to both DE-CT and 120kVp SE-CT. For DE-CT, a 140kVp tube potential in combination with a gold-tin split filter in longitudinal direction (TwinBeam, Siemens Healthineers) was used to create a L and H, mixed (0.2H+0.8L), composed (pooled L+H raw data), VMI (60-95keV) and rho reconstruction.
The mean CT number in HU of the inserts for the DE-CT reconstructions were compared with the SE-CT calibration curves in the treatment planning system (TPS, Varian Eclipse®) using the root-mean-square-error (RMSE). A volume-modulated-arc-therapy plan in the brain (stereotatic-radiosurgery) and oral cavity of the HN phantom was created on the SE-CT and re-calculated on the DE-CT reconstructions. A local 3D 1%/1mm gamma index was calculated. Couch shifts between setup markers and the two plan iso-centers were calculated in the TPS. Repeated cone-beam CT (CBCT) based auto-alignment on bony anatomy was carried out at the linac (Varian TrueBeam®) from setup markers using SE-CT, rho and VMI as reference.
Results: A minimum RMSE of 34HU (MD), 35HU (RED) and 28HU (SPR) was found for a VMI reconstruction at 75keV which is within SE-CT protocol variations. The largest deviations were mainly seen at high-density inserts across reconstructions. The minimum RMSE correlated with the highest gamma pass-rate of 98.2% for the oral plan whereas no clear correlation was found for the brain plan. Deviations between TPS and CBCT-rho/VMI matches were <1.6mm (i.e. within setup uncertainty) with no observed dependence on reference tissue contrast.
Conclusions: DE-CT reconstructions can be safely implemented in RT. A mono-energetic reconstruction around 75keV was suggested for dose calculations. No apparent dependence in IGRT accuracy with alternating tissue contrast was observed for the DE-CT reconstructions investigated.

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THE BERGEN PROTON-CT PROJECT
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In particle therapy, proton or ion beams deposit a large fraction of their energy at the end of their paths, i.e. the delivered dose can be focused on the tumor, sparing nearby tissue due to a low entry and almost no exit dose. A novel imaging modality using protons promises to overcome some limitations of particle therapy and will allow the full exploitation of its potential. Being able to position the so-called Bragg peak accurately inside the tumor is a major advantage of charged particles, but incomplete knowledge about a crucial tissue property, the stopping power, limits its precision. The conversion of photon attenuation maps from computed tomography (CT) scans into relative stopping power introduces range uncertainties. A proton/helium-CT scanner provides direct information about the stopping power and has the potential to reduce range uncertainties significantly, but no proton-CT system has yet been shown to be suitable for clinical use.

For a proton-CT scan the particles – typically protons or alpha particles - need to be energetic enough to traverse the patient completely, i.e. the Bragg peak is positioned in a detector. The trajectory of every outgoing proton, as well as the residual energy/range, is measured. The calculation of the proton trajectory inside the target region and the measured residual proton energy/range provide a 3D-map of the relative stopping power. During a scan, the patient needs to be rotated to obtain projection data from a set of different angles.

A (clinical) prototype of an extremely high-granularity digitial tracking calorimeter has been designed and is being constructed in Bergen. The latest developments in Monolithic Active Pixel Sensors (MAPS) technology allow the fabrication of extremely-high granularity, low material budget and large area silicon detectors with integration times of microseconds and zero-suppression of the data on the sensor itself. The prototype is a silicon/absorber sandwich calorimeter with 41 sensitive layers of MAPS.

A complete CT reconstruction of a simulated anthropomorphic paediatric head phantom shows that the concept of a single-sided detector setup and realistic pencil beam parameters gives a spatial resolution sufficient for proton therapy treatment planning.

The expected performance based on simulations, first beam test results and the status of the construction will be presented, e.g. proton tracking accuracy, dE/dx capability, rate capability, radiation hardness and 3D spatial resolution after CT reconstruction.

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WEPL ASSESSMENT VIA FLAT PANEL PROTON RADIOGRAPHY WITH A PATIENT SPECIFIC IMAGING FIELD

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Purpose: Water-equivalent path length (WEPL) measurements via flat panel proton radiography (FP-PR) have the potential to enable the detection of proton range errors, the basis of high-precision proton therapy irradiations. Accurate WEPL measurements via FP-PR can be obtained with several energy layers, which impose a high imaging dose. To minimize imaging dose, in this study we propose a FP-PR method for accurate WEPL determination based on a patient specific imaging field with a reduced number of energies (n).

Materials and methods: Patient specific FP-PRs were simulated and measured for a head and neck phantom. An energy selection algorithm estimated at each spot coordinate the lowest energy required to cross the anatomy using a water equivalent thickness map and a FP calibration dataset. At each coordinate, higher energies in steps of 3 MeV were limited to specific numbers (n = 26, 24, 22, 20,…, 2 for simulations, n = 10 for measurements). As a result, patient specific FP-PR imaging fields contained different spot patterns for each energy layer, according to the individual anatomy. WEPL maps were reconstructed using the FP calibration.

The impact of the energy selection algorithm was evaluated via simulations and experiments with mean absolute WEPL differences (MAD) between WEPL maps obtained from patient specific FP-PRs and a reference FP-PR with a complete set of energy layers where no spot-wise energy selection was applied.

Results: The comparison between patient specific and reference FP-PRs via simulations resulted in MADs between 2.1 mm and 2.5 mm for 26 ≥ n ≥ 18. MADs were between 3.0 mm and 5.2 mm for intermediate values of n (16 ≥ n ≥10). Largest MADs between 6.3 mm and 21.0 mm were obtained with the smallest n values (8 ≥ n ≥ 2).

The experimental delivery of FP-PRs took about 40 minutes per FP-PR, and the patient specific FP-PR (n=10) carried an imaging dose 5 times smaller than the reference FP-PR. A MAD of 7.2 mm was obtained between reference and patient specific scenario (n=10).

Conclusion: A method to perform WEPL measurements via FP-PR with a reduced number of energies selected in accordance to the individual patient anatomy has been proposed and investigated in silico and experimentally. Patient specific FP-PRs could be used as an in vivo range verification tool within online adaptive proton therapy workflows.

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MYQA SRS DETECTOR: CLINICAL APPLICATION IN SRS/SBRT PATIENT QA

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Purpose: A new high resolution device, provided by IBA Dosimetry, was tested as pre-treatment patient specific Quality Assurance (QA) for Stereotactic Body Radiation Therapy (SBRT)/Stereotactic Radiosurgery (SRS).

myQA SRS detector assures high accuracy in dose evaluation for very small volumes and very high dose involved in SBRT/SRS, as well as radiochromic film. However, the new device goes beyond film's limitations connected to time consuming, uncertainties in handling, calibration, and development.

Material and methods: 40 SBRT/SRS VMAT (Volumetric Modulated Arc Therapy) treatment plans for lung, spine and brain were selected and dose distributions calculated on the patient's CT by AcurosXB v.15.6 algorithm, were analysed using gamma analysis index.

Plans were delivered across myQA SRS detector, located inside myQA SRS phantom, serving as build-up and backscatter material.

The measurement sensors of myQA SRS are monolithic solid-state semiconductor sensors arranged in a 2D array and the detector is optimized to measure 2D dose maps of small fields with high resolution. The sensor layout is a grid of 300×350 pixels spaced of 400 μm in an area of 120 mm×140 mm (active area).

Verification plans were created and calculated in the myQA SRS phantom, using AXB and the "field based" setting. 2D measured dose distribution at the isocenter plane, for each arc, was compared with the calculated field dose exported on the myQA platform from TPS. A global gamma analysis was performed using 2%-2mm criteria, with 5% threshold dose.
Results were compared to pre-treatment verification on the same plans performed with our routinely used system electronic portal imaging device (EPID) and analysed with Portal Dosimetry (PD, v. 2.22.5.0), using a local gamma analysis (2%-2mm), with a 5% threshold dose.
A gamma passing rate ≥95% was considered in this study for both used methods.
Results: All plans passed the gamma evaluation with both myQA SRS and EPID, showing a mean gamma passing rate of 99.50% [from 97.8% to100%] and 99.34% [from 97,5% to 100%], for EPID and myQA SRS, respectively. All verified plans satisfy the established gamma analysis passing rate ≥ 95%.
Conclusions: myQA SRS measurements demonstrated excellent agreement versus TPS doses and EPID's results. The main advantage of the new tested device is in the dosimetric detail and the ability to verify dose distribution accuracy in minutes rather than hours and with the necessary spatial resolution for SRS/SBRT QA.

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THE RIGHT TIMING FOR BEAMS CALIBRATION OF TRUEBEAM LINEAR ACCELERATORS

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Purpose: The aim of this work is to define the right timing for preventive beams calibration throughout the year, for TrueBeam (Varian Medical Systems, Palo Alto, CA, USA) linear accelerators (Linacs), using the daily output measurements performed with Machine Performance Check (MPC) tool.
Material and methods: Three TrueBeam Linacs version 2.7, all placed in Humanitas ICC radiotherapy department, were equipped with the aS1200 portal imager. The MPC application is an automated tool, integrated into the three Linacs, allowing to perform a check of beam output, uniformity and various geometric parameters, utilizing a dedicated phantom and the imaging system. All daily output data, measured with MPC from July 2020 to October 2021, were exported and plotted for all energies investigated and all the Linacs to visualize the trend.
Results: The output of the Linacs under examination showed an increase for all photon and electron energies (on average 3.2% and 3.27% per year, respectively), in agreement with the literature findings. The increasing trend was the same not only for all the energies of the same Linac but also for the three different Linacs, so output data of a single energy were representative of all the others and of all the TrueBeam Linacs. Moreover, output calibrations and subsequent MPC re-baselines resulted in sudden drops of output trend towards baseline. This allowed to identify the dates of absolute dose calibration, performed according to the IAEA TRS-398 protocol. On the basis of the values measured monthly with the ionization chambers and daily with MPC, during the investigated period, the output needed to be adjusted once every 3-6 months to stay within the recommended tolerance limits, also taking into account any maintenance interventions on the Linacs (such as change of monitor chambers or MV panel replacement due to the reduction in panel sensitivity over time).
Conclusions: In this study, the MPC daily output measuring tool provided huge support for establishing the right timing for output adjustments and most importantly to improve dose control. The analysis of common trends to TrueBeam Linacs is essential for physicists in order to have a longer-term view of the behaviour of the treatment machine and to plan preventative interventions and beams calibrations throughout the year, before reaching the tolerance levels.

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DOSIMETRIC EVALUATION OF DOSE CALCULATION ACCURACY IN THE PRESENCE OF METALLIC PORT IN TEMPORARY TISSUE EXPANDERS

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Aim: Temporary tissue expanders (TTE) with a metallic port are currently a wildly used option for mastectomy patients. The magnetic properties of the port allow it to be filled with saline. However, artefacts in computed tomography (CT) and treatment planning systems (TPS) calculation inaccuracy for high-density materials may contribute to the unexpected dose delivery. This study aims to compare TPS calculations with radiochromic film measurements in the presence of metallic port in breast TTE.
Material and methods: The study tested two TTEs with integrated ports (Nagor IF-1/Mentor IF-2) and one TTE with a distal port (Mentor DF). Four breast phantoms were fabricated from paraffin: three with each type of TTE and a reference one without a metal port (RF). A 5mm thick thermoplastic bolus covered each phantom. Eight treatment plans were prepared for each phantom in the Eclipse TPS (v 15.6, Varian Medical Systems). Calculations were based on the CT extended calibration curves with high Z materials (up to 10 000 HU). 3D-CRT and VMAT plans were made for 6MV, 6MV FFF, 15MV beams and the AAA calculation algorithm. For 6MVFFF beam, dose calculations with Acuros XB algorithm were added. 11 to 13 measuring points were marked on each phantom, where Gafchromic EBT3 films were placed during irradiation. Dose measured and calculated in TPS were compared.
Results: For RF, 6MV and 6MVFFF beams and both algorithms, the dose differences did not exceed 4% (3D-CRT) and 3% (VMAT). These differences increased to 4% (3D-CRT) and 6% (VMAT) when 15MV was analyzed. For phantoms with ports (IF-1, IF-2, DF), for 75% of all measurement points the differences between measured and calculated doses did not exceed 4% and were independent of the algorithm used. For individual phantoms, the differences below 4% were obtained for 58% and 80% of points for phantoms IF-1 and IF-2 and 86% for the DF phantom. The calculated dose higher than the measured of more than 4% (up to 17%) was obtained in 60% of the points located near ports. The most significant differences (exceeding 8%) were noticed for integrated ports and both calculation algorithms. The results for the Acuros XB algorithm yield more outliers compared to the data for the AAA algorithm. Overall, slightly better agreement between measurements and calculations was obtained for the 6MV beams.
Conclusions: Better agreement between calculations and measurements was expected. The differences strongly depend on the radiation energy and the distance from ports.

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CLINICAL EVALUATION OF NOVEL DWI SEQUENCE ON RECTAL CANCER PATIENTS IN A 0.35 T MR-LINAC SYSTEM

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Purpose: Magnetic resonance guided radiotherapy (MRgRT) allows online adaptation based on the daily anatomy as well as on quantitative MRI detectable tissue variations. Diffusion Weighted Imaging (DWI) may allow to exploit the possibility to assess treatment response along treatment. The aim of this study is to evaluate the use of DWI on a 0.35 T MR-Linac system to detect tissue variation during treatment.

Material and methods: Six rectal cancer patients enrolled in an ongoing clinical trial (simultaneous integrated boost: 45 Gy to the pelvis and 55 Gy to Gross Tumor Volume (GTV)) have been included in this analysis. The trial provides a boost on the GTV (60.1 Gy) from the 11th fraction in case of Early Regression Index (ERI) higher than 13.1 ("not-responder"). The 0.35 T optimized DWI sequence at is acquired after treatment delivery on the central GTV slice during the pre-treatment simulation and every five fractions and is used to calculate Apparent Diffusion Coefficient (ADC) map. ADC map is then generated with ImageJ software using a mono-exponential model. Results have been analysed in terms of mean ADC values variation along the fractions for each patient. ADC values were calculated not only on the GTV but also on the right femoral head (FH) as a reference for ADC constancy.

Results: Six rectal cancer patients were enrolled in this analysis, only 2 resulted to be "not-responder". The percentage variation of GTV ADC values between fraction 10 and 15 was always within 66% for "responder" and greater than 99% for the "not-responder". The standard deviation (SD) of GTV ADC value was 0.6: 0.4 and 0.8 (10^(-3) mm^2/s) for "responder" and "not responder", respectively. When the FH is considered instead, the ADC remains constant throughout treatment (0.30±0.08 10^(-3) mm^2/s).

Conclusion: These preliminary results seem to suggest a different behaviour of mean GTV ADC values between "responder" and "not-responder" rectal cancer patients included in this clinical trial. ADC values can potentially detect and quantify tissues changes in GTV caused by ongoing treatment. Further analysis of the remaining 56 patients who will be enrolled in the clinical trial could confirm these promising preliminary results.

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INTER AND INTRA-FRACTION MOTION IN 3-FRACTION SBRT FOR PROSTATE CANCER: DOSE DEVIATIONS IN ORGANS AT RISK

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Purpose: In 15 patients out of 53 enrolled in a prospective study of SBRT for prostate cancer, the impact of organ motion on the delivered dose on OARs has been investigated.

Material and methods: Patients were prescribed 40Gy/3 fractions to deliver at least 36 Gy to 95% of the prostate while respecting dose constraint on OARs; rectal D1cc<30Gy; bladder D1cc<38Gy, urethra D0.1cc<33Gy. Fiducials markers, urethra catheter and rectal spacer were placed. Treatments were delivered by a VMAT 10 MVFFF technique; CBCTs were acquired before treatment (initial), between each arc and at the end of the treatment (final). CBCT images were aligned to planning CT based on both catheter and fiducials positions. No correction for rotation was applied. After CBCT HU calibration, original plans were recalculated on both the initial (after set up correction) and the final (after the end of treatment) CBCT for each patient/treatment session. Inter and intra fraction deviations were evaluated. Selected dose/volume metrics of OARs were extracted from the DVHs of the various plans and compared; the Mann Whitney test was used to assess the significance of the differences observed ($p \leq 0.05$).

Results: *Inter-fraction:* Doses calculated on CBCT initial were statistically different from the planned ones. Median plan D1cc rectum (Gy), D1cc bladder (Gy) and D0.1cc urethra (Gy) were 29.8, 37.8 and 24.7 respectively. Median initial D1cc rectum (Gy), D1cc bladder (Gy) and D0.1cc urethra (Gy) were 30.9, 38.9 and 33.8 respectively.

Intra-fraction: Doses calculated on CBCT final were not statistically different from the initial ones. Median final D1cc rectum (Gy), D1cc bladder (Gy) and D0.1cc urethra (Gy) were 30.2, 39.0 and 34.1 respectively.

Conclusion: Doses calculated on initial CBCT are higher than the planned ones, this systematic trend could be due to differences in calculation between CT and CBCT images and inaccuracy in CBCT calibration. However, ΔD ranges from 1.15 to 2.25 Gy for the whole course of treatment. Not significant differences between doses calculated on CBCT final and CBCT initial indicate that intra-fraction motion may not be an issue provided the use of urethra catheter, fiducial markers, rectal spacer and a fast delivery technique.

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COMPARISON BETWEEN ONCENTRA MASTERPLAN COLLAPSED CONE AND ECLIPSE AAA ALGORITHMS AT EXTENDED SAD

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Purpose: Among the various techniques proposed for total body irradiation (TBI) treatments, the most commonly used remains the one based on parallel opposed anterior/posterior fields at extended source-axis distances (SAD).

Traditionally, dose calculation at an extended SAD is based on a point-dose calculation approach. Although this method can be effective in one point, it fails to provide a complete dose distribution. To overcome this issue, several studies assessed the dose calculation accuracy of commercial treatment planning system (TPS) at extended SAD.

In this study, we compared the Eclipse pencil beam superposition/convolution algorithm (AAA) with the Oncentra MasterPlan Collapsed Cone, in TBI condition for a SAD of 365 cm. Comparisons were made in term of relative and absolute dose, taking as reference the dose measured in patient or in phantom.

Material and methods: Simulations and measurements were performed following the TBI setup: field of 40×40 cm2 and SAD of 365 cm, with different phantoms:

- water-equivalent cube phantom for the tissue maximum ratio (TPR). Dose measurements were performed in a 30×30×30 cm3 solid water slab phantom.
- water equivalent cylindrical and elliptical phantom for the midplane dose calculation in function of the phantom radius and of the ratio of the two axes of symmetry, respectively
- IMRT CIRS phantom for midplane dose measurements

Moreover, 20 patients already treated were re-simulated analyzing absolute and relative dose.

Results: Measurements of absolute dose in solid water slab phantom (TPR) and in CIRS phantom showed a discrepancy (in term of calculated MU) of:

- -0.5% for Oncentra
- -2.3% for Eclipse

Discrepancies between Oncentra and Eclipse in cylindrical and elliptical phantom increased both with the reduction of radius (cylindrical) and with the reduction of the ratio of the two axis of symmetry (elliptical) from 2% up to 6%.

Relative dose calculated in patients with Oncentra and Eclipse was comparable (±2%).

Conclusion: The agreement in absolute point dose between Oncentra and measurements in patient and in phantom was less than ±1%.

By contrast, prescribing a dose value in the midplane dose point, Eclipse shows a general underestimation of MU ranging from 2% to 6%. Consequently, a model for the correction of the MU calculated by Eclipse has been developed, depending on thickness and on ratio between thickness and width of patients.

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MANAGEMENT OF CBCT IMAGING IN RADIOTHERAPY TREATMENT OF PROSTATE CANCER PATIENTS

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Purpose: Due to extensive daily CBCT imaging in radiotherapy, the need for a protocol optimization has been recognized, inline with international recommendations. The aim of this study was to investigate positioning accuracy, safety margins and absorbed dose- image quality dependence for prostate cancer radiotherapy treatment and different imaging protocols.

Material and methods: The systematic and random set-up errors were obtained from treatment CBCT images for 30 patients, who followed dietary advices. All patients were treated on Varian TrueBeam, with VMAT with simultaneous integrated boost 70/57.4/50.4 Gy to the prostate, seminal vesicles and pelvis in 28 fractions, respectively. In average, 30 CBCT scans were acquired per patient (ranging from 28-35 CBCTs). All patients were treated in supine position using immobilization devices for knee and ankle support. The PTV margins were from 7-10 mm. CBCT protocols used were default pelvis and large pelvis. Both protocols were investigated in following manner: the point absorbed dose was measured by cylindrical ionization chamber in target center and all organs at risk in anthropomorphic pelvic phantom; standard image quality parameters were measured with Catphan phantom and analyzed by Smari software.

Results: The overall mean set-up deviation was 1.22 mm (vertical), -2.20 mm (longitudinal) and -0.28 mm (lateral). The maximum difference in set-up correction was from -1.68 cm to +1.64 cm. The results for population systematic and random errors were 2.91 mm and 3.25 mm (vertical), 2.82 mm and 2.90 mm (longitudinal), 3.33 mm and 3.62 mm (lateral), respectively. The calculated PTV margins according to Van Herk formula were 9.56 mm (vertical), 9.07 mm (longitudinal) and 10.87 mm (lateral). From 30 acquisitions with pelvis CBCT protocol, the accumulated absorbed dose to target was 72 cGy and to organs at risk was 75 cGy for rectum, 77 cGy for bladder, 130 cGy and 118 cGy for right and left femoral heads. From large pelvis CBCT protocol, the accumulated absorbed dose was in average 2.2 times higher than with pelvis CBCT protocol (due to larger tube voltage and current). The image quality from both CBCT protocols show no significant differences.

Conclusion: The use of smaller PTV margins must be justified by setup error data, and carefully implemented, followed by daily CBCT imaging. Based on the results of absorbed dose to point and image quality correlation, in our case use of pelvis CBCT protocol is recommended. It should be borne in mind that any radiation must be justified.

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TRANSFERABILITY OF KNOWLEDGE BASED (KB) PLAN PREDICTION MODELS FOR RIGHT-WHOLE BREAST IRRADIATION (R-WBI)

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Purpose: To quantify inter-institute variability and evaluate plan transferability in R-WBI with tangential fields (TF) through KB-approach.

Materials and methods: Ten collaborating institutes built their R-WB-TF (3DCRT FiF and/or wedged) KB models by using RapidPlan (Varian Inc., V16.1 or earlier), following previously shared methods, including contouring (national guidelines for CTV/PTV/OARs), number of patients (>30), techniques (wedged or Field in Field) and model training and validation procedures. Models were tested on 20 additional patients from the same Institutes (two patients each), exporting DVH prediction bands of OARs (heart, ipsilateral lung, contralateral lung and contralateral breast). Inter-institute variability was quantified by looking at: 1) SD across models of predicted DVHs; 2) SD of predicted Dmean of OARs. The transferability of models among Institutions was evaluated by the overlap of the geometric Principal Component 1 (PC1) of each model when applied to the test patients of the other 9 Institutes. Transferability cross-validation was further investigated on a larger population for the only model showing poor transferability (Model_INST6) against one of the models with high transferability (Model_INST3): 80 patients for each of the two Institutes (Dataset_INST6 and Dataset_INST3) were considered.

Results: The overall inter-institute variability of DVH and Dmean ipsilateral lung dose prediction was around 2% (20%-80% dose range) and 0.59Gy respectively (1SD) for a 40Gy/15fraction schedule, while it was < 0.2Gy for other OARs. INST 6 showed a different contouring attitude, showing no overlap between PTV and ipsilateral lung. Once excluded INST 6, the predicted ipsilateral lung Dmean was correlated with PTV D99% (median value, R^2= 0.78). Concerning transferability, PC1 values were always within the range of applicability for 7 models: for 2 models it was outside in 1 out of 18 cases while failed in 7/18 cases for INST 6. The Model_INST6 vs Dataset_INST3 analysis

revealed PC1 out of range values in 41/80 cases, confirming the poor transferability of Model_INST6. On the other hand, Model_INST3 vs Dataset_INST6 analysis showed out of range PC1 in only 14/80 cases, showing better transferability.

Conclusions: Results show a limited Inter-institute variability of plan prediction models and a sufficiently high inter-institute transferability, excepting one of ten institutes. These results encourage future investigations in generating benchmarks for plan prediction in WBI incorporating inter-institute variability with potentially relevant applications in QA audits and large-scale KB-driven automatic plan optimization.

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ASSESSMENT OF DIFFERENT METHODS OF MEASURING THE DOSIMETRIC LEAF GAP (DLG) FOR VARIAN TRUE BEAM HD

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Purpose: Transmission through the round leaf ends in the Multi-Leaf Collimator (MLC) is a problematic issue to take into account when commissioning algorithms in a Treatment Planning System. Varian works with a parameter called Dosimetric Leaf Gap (DLG) and propose its own method of measuring it, but the actual value should be the one that makes the dose calculations as accurate as possible.

The objective of this study is to evaluate how accurate the Varian-proposed method of measuring the DLG is, as well as comparing the value of DLG obtained to the one reached through four other ways. It is also discussed the variation of such parameter with MLC modulation and the planning technique (IMRT/VMAT).

Material and methods: Five different methods of measuring the DLG for Acuros (AXB) were used.

1) Varian-proposed method, which consists in several Sweeping-Gap plans (with 2 to 20 mm gaps) measured with an ionization chamber (PTW-Semiflex-3D).
2) Creation of 20 plans (10 IMRT and 10 VMAT) with different field size, pathologies, dose per fraction and MLC modulation. Calculate each of those plans with ten different DLGs (from 0 to 2 mm). Measuring those plans with portal dosimetry (PD) and evaluating a 2mm–2% (local) gamma passing rate (GPR). Find the value for which the GPR maximizes.
3) Measurement of those same 20 plans with Octavius 4D (srs1600) and also evaluating a 2mm–2% (local) GPR.
4) Measurement of a dose point of those same 20 plans with an ionization chamber (PTW-PinPoint-3D).
5) Measuring a Picket Fence plan with Octavius 4D (srs1600)

Results: The obtained DLGs for our treatment energies are:

For 6X we obtained 0,84 mm (Varian method); 1,15 mm (PD); 1,35 mm (Octavius1600); 0,95 mm (ionization chamber) and 1,35 mm (PicketFence).

For 6FFF we obtained 0,74 mm (Varian method); 0,05 mm (PD); 1,50 mm (Octavius1600); 0,98 mm (ionization chamber) and 1,30 mm (PicketFence).

For 10X we obtained 0,95 mm (Varian method); 1,60 mm (PD); 1,20 mm (Octavius1600); 1,45 mm (ionization chamber) and 1,25 mm (PicketFence).

Conclusions: Optimal DLG highly depends on the method of measurement used and Varian method seems to underestimate the value, not achieving the optimal dose calculations. A very wide range of optimal DLG are observed, changing a lot between methods and also between plans. Our hospital took a weighted average value from the five results for each energy. Other conclusion is that IMRT plans are more DLG-dependent than VMATs.

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NATIONAL AUDIT ON DOSE DELIVERY IN RADIATION ONCOLOGY

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Purpose: Dosimetry audits are an important tool for verification of treatment planning system (TPS) modelling and treatment delivery. Comprehensive on-site audit methodology was developed, and national audit performed under the International Atomic Energy Agency project CRO6019.

Material and methods: Implementation of advanced radiation oncology techniques in Croatia began during past decade. Currently six out of seven sites are performing advanced techniques. This requires rigorous absorbed dose distribution verification prior dose delivery.

On-site audit was performed using 2D methodology due to its feasibility for transportation. Main part of the methodology development was to correlate 3D and 2D verification methodologies. Additionally, radiochromic films were used.

Audit had two parts: absorbed dose measurements in reference conditions and 2D verification of absorbed dose distributions (reference field, five fields pyramid, clinical dose distributions: head and neck and prostate). Calculation and experimental verification of dose distributions using audited sites' devices where prerequisite for audit. Sites were obliged to calculated absorbed dose distributions prior experimental part of the audit.

Results: Results can be divided in three categories: in-house development of comprehensive methodology to be applied for on-site audit, questionnaire on application of advanced radiation oncology techniques and validation of data acquired during the audit. Thorough methodology development multiple comparisons were performed e.g., 3D true and perpendicular composites, 2D perpendicular composites at 0°and 90°, ionization chamber true and perpendicular composites. Experimental results confirmed feasibility of 2D dosimetry for the audit.

Answers on the questionnaire shown that there is single linear accelerator dedicated to application of advanced techniques at each site. Two sites perform VMAT only, two both VMAT and IMRT, and two IMRT only. Three sites use 6 MV X-ray beams and three 6MV and 10 MV. Five sites use advanced calculation algorithms (Monte Carlo and Acuros XB). Pre-treatment verifications are performed regularly at each site. Half of sites perform it using portal dosimetry. Tolerance criteria used are as follows: 3%/2mm (4), 2%/2mm (1), and 3%/1mm (1). Gamma passing rate higher than 95% is criterium at all sites.

Despite complex processing methodology required, radiochromic film dosimetry had proved dosimetric potentials to supplement audit methodology in non-reference conditions.

Comprehensive analyses of acquired data have shown acceptable results of majority of audited sites.

Conclusions: National audit had proved that pre-treatment dosimetry at national level is performed in suitable way. Nevertheless, there is a room for improvements and optimization is required.

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DOSE QUANTIFICATION FROM DAILY CBCT EXAMS DURING VMAT PROSTATE RADIOTHERAPY TREATMENTS USING AN INNOVATIVE PLASTIC SCINTILLATING DETECTOR

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Purpose: Since the Image Guided Radiotherapy (IGRT) has become a necessary tool in order to achieve high precision radiotherapy treatments, it became more and more important to quantify the dose due to imaging techniques such as Cone-Beam Computed Tomography. In this context, this study aims to assess the delivered dose due to daily CBCT during prostate VMAT treatment and help to determine the total dose delivered to the volumes.
Materials and methods: The study was carried on a Novalis TX (Varian Medical System, Palo Alto, USA) using a Fibermetrix (Strasbourg, France) plastic scintillation dosimeter (PSD) system placed under the treatment table. The sensitive part of the PSD is 1mm of diameter and 1m long in order to take account of the complete length of the irradiated field during CBCT acquisitions. The PSD is calibrated according to the IAEA human health reports n°5 on the status of computed tomography dosimetry for wide cone beam scanners in order to measure the delivered dose and CTDI. In order to evaluate the calibration, the dose measured with the PSD was compared to the dose measured by a pencil ionization chamber of 100mm in a CTDI fantom placed at the isocenter, on the treatment table. Two CBCT protocols used in prostate VMAT treatments were used during the study : Pelvis and Large Pelvis. The dose and CTDI was measured for the two protocols and compared to OAR and target volumes planned dose for prostate VMAT radiotherapy.
Results: The mean difference between the dose measured by the PSD system and by the ionization chamber were -4.4% and -5.4% for the Pelvis and Large Pelvis protocols. For the Pelvis CBCT protocol, the dose and the CTDI measured were respectively 71.1mGy and 17.1mGy. For the Large Pelvis protocol, the dose and the CTDI measured were respectively 143mGy and 34.9mGy.
Conclusion: Since the dose difference with the ionization chamber is about -5%, the PSD system used in this study is an effective way to measure the dose due to CBCT. The results of the study highlights the importance to assess the delivered dose in IGRT, specifically when it comes to prostate VMAT radiotherapy due to the daily CBCT acquisitions.

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THE BENEFITS OF APPLYING DOSE AND IMAGE QUALITY OPTIMISATION STRATEGIES FROM DIAGNOSTIC IMAGING IN A RADIOTHERAPY SETTING

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Purpose: Computed tomography (CT) is an integral component of the radiotherapy planning process and X-ray imaging systems such as cone-beam CT (CBCT) are used to confirm patient positioning prior to commencing treatment. The radiation dose from CT and CBCT, although comparable to CT in diagnostic imaging, is orders of magnitude lower than the treatment dose. Consequently, optimisation of imaging protocols is often not considered to the same (or any) extent in radiotherapy as in diagnostic radiology. The aim of this work was to highlight the potential for reducing cumulative imaging dose over the course of treatment while also providing the required image quality.
Material and methods: Local protocol-specific CT dose indices were established using the method published by Wood et al (Phys Med Biol, 63, 2018). The CT Brain dose index was found to be almost 50% higher than the proposed dose index. The CT Head and Neck dose index was found to be 70% lower than the proposed dose index. A series of CT dosimetry and image quality measurements were performed using both protocols to identify the parametric adjustments required to optimise both patient dose and image quality.
Similarly, by reducing the rotational arc and/or increasing the gantry speed of the existing CBCT protocols, a dose reduction of up to 50% was achieved without loss of information required for verification of patient position.
Results: Three common radiotherapy treatment protocols were simulated to quantify the impact of the optimisation project on cumulative imaging effective dose: (1) breast treatment of 50Gy in 25 fractions with CBCT on day 1-4 and subsequent weekly verification, (2) head and neck treatment of 60Gy in 30 fractions with CBCT on day 1-4 and subsequent weekly verification, (3) prostate treatment of 60Gy in 20 fractions with daily CBCT. The absolute and percent reduction in effective dose was (1) 43.3mSv and 46.1% for breast, (2) 2.5mSv and 29.4% for head and neck, (3) 134mSv and 58.6% for prostate.
Conclusions: The results demonstrate the significant potential reduction in cumulative effective dose when imaging protocols in radiotherapy are optimised. The project also highlighted protocols with sub-optimal image quality, where an increase in dose was justifiable in order to improve the image quality for treatment planning. Ongoing monitoring of dose indices and image quality metrics, with input from diagnostic and radiotherapy physicists, will ensure optimal performance of the imaging protocols on an ongoing basis.

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VALIDATION OF A SECONDARY DOSE CALCULATION SYSTEM FOR VOLUMETRIC MODULATED ARC THERAPY QUALITY ASSURANCE

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Purpose: To evaluate the Mobius3D (MobiusCalc and MobiusFX) second-check dosimetry system (Varian, a Siemens Healthineers Company) by comparing the 3D dose distribution calculated by the system with the Delta4 Phantom+ (ScandiDos AB, Uppsala, Sweden) dose measurements.
Materials and methods: Ten volumetric modulated arc clinical treatment plans (prostate, pelvis, H&N and lung stereotactic) performed with the treatment planning system (TPS), Varian Eclipse with the AAA and AcurosXB dose algorithms were selected for the study. The dose distributions were recalculated on the Delta4 Phantom+ by the TPS and the MobiusCalc, an automatic 3D plan re-calculation starting from the DICOM RTPlan files in the patient CT using independently verified beam models and a GPU-accelerated collapsed-cone (CCC) dose algorithm.
The plans were delivered to the Delta4 Phantom+ with 6MV or 6MV FFF beams on a Varian TrueBeam Linac. MobiusFX automatically determines the delivered fluence distribution by means of the machine-measured log files of each delivery and using the CCC dose algorithm to interpret 3D delivered dose in the patient.
The calculated doses (TPS, MobiusCalc and MobiusFX) were then compared to the measured ones in terms of median dose and dose gamma analysis metric.

Results: The median dose average difference between TPS and measurements was -0.1±0.2%. Differences ranged from -0.3% to + 0.2%. The median dose average difference between MobiusCalc and MobiusFX and measurements were -0.6±0.6% and -0.6±0.7%, respectively. A maximum median dose difference of 0.2% was found between MobiusCalc and MobiusFX.
Average global gamma pass rate, using a criteria of 2%-2mm, was 94.0±4.9% and 94.2±4.8% for MobiusCalc and MobiusFX to measurements comparison respectively. Results for TPS were 99.8%±0.2%.
Mobius3D (either MobiusCalc than MobiusFX) vs. measurement differences ranged from 86.6% to 99.4%. The best results were obtained for prostate plans; the worst for the pelvis ones.
Using criteria appropriate to a secondary check verification (3%-3mm), the average global gamma pass rate is always greater than 97%.
Conclusions: Mobius3D is an adequate independent secondary check system for the dose distribution of VMAT plans.

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COMPARATIVE TREATMENT PLANNING STUDY FOR DOSE REDUCTION IN CIEDS IN PATIENTS WITH ESOPHAGEAL OR NASO- AND OROPHARYNGEAL CARCINOMA

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Purpose: In radiotherapy of patients with cardiac implantable electronic devices (CIED) dose to the CIED should be limited to a maximum of 2Gy according to national and international guidelines. The aim of this project was to determine a suitable irradiation technique that leads to a significant dose reduction in CIEDs.
Material and methods: For 14 patients with esophageal or naso- and oropharyngeal carcinoma, treatment planning was performed in the treatment planning system (TPS) Monaco (Elekta, Sweden) using 6MV photons with flattening filter (FF) and without (FFF) and different VMAT techniques (dual/triple, full/partial, one/several Arcs). 8 different plans were created per patient. Dose prescription was 25x1.8Gy for esophageal and 35x2Gy for naso- and oropharyngeal carcinoma. For all plans, an attempt was made to limit the maximum dose to the implant to <2Gy. Plan quality parameters like dose coverage (PTV95%), homogeneity (HI), conformality Index (CI), dose maximum (Dmax) and mean dose (Dmean) at the CIED were used to determine the best plans. The best 4 plans of each patient were used for descriptive statistical evaluation. To test whether the null hypothesis "Plan quality and CIED dose do not differ for treatment plans with FF or FFF" was true, the Wilcoxon signed rank test for each parameter was applied with a significance level of α=5%. To compare Dmax and Dmean despite the differences in prescribed dose, the data were normalized to value in the FF mode. The Bonferroni-Holm correction was applied to control maximum experimentwise error rate for multiple testing.
Results: In terms of PTV95%, CI, and HI, the final 4 treatment plans of each patient were essentially equivalent. After Bonferroni-Holm correction, the only significant difference between FFF and FF was observed in CIED dose. FFF plans resulted in significantly lower Dmax compared with FF mode in 21 of 28 plans (75%). Twice as many FFF plans could be pushed below a Dmax of 2Gy compared to FF.
Conclusions: The study showed that significant reduction in the CIED dose can be achieved for patients with esophageal or naso-oropharyngeal carcinoma using treatment planning in FFF mode without compromising plan quality. It has no significant influence whether irradiation is performed with one or several partial triple Arcs.

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OPTICAL SYSTEM FOR PRECISE MEASUREMENT OF THE ACCELERATOR'S MECHANICAL ISOCENTER

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Purpose: Safety and effectiveness of the stereotactic techniques requires high geometric precision of irradiation. The AAPM142 report recommends that the diameter of the mechanical isocenter (for gantry, collimator and treatment table) should not exceed 1mm. We present a mobile optical device designed for fast, precise and independent measurement of the position of mechanical isocenter.
Material and methods: The system consists of a two cameras, a workstation and light source. Two cameras are mounted on a horizontal bar which is located on the mobile platform. The design enables the measurement of all rotational movements of the accelerator, gantry, collimator and table without having to change the position of the system. During the measurement the cameras track the position of the 3D marker attached to the moving part of the accelerator. The analysis of the recorded images with the software allows to determine the marker's center and thus to determine the curve along which the rotating element moves. During one rotation about 1,200 points are registered. Then, the analysis of the registered motion is performed with the software written by authors. A circle is fitted to the set of recorded points for each 30o of segment. The center of each circle determines the current center of rotation of a given element for the angle in the middle of the sector. The calculation model has been checked by stimulating the accelerator rotation. The position of the axis of rotation was described by a harmonic function with a 2 mm amplitude. In order to validate the optical system's operation, a device simulating the rotation of the arm, collimator and therapeutic table was constructed. The simulator was attached to a base. It was possible to change the position of the base in three directions with a step every 0.01 mm. The results of accelerator's isocenter measurements are presented on a 3D chart. We performed isocenter measurements for 5 linear accelerators installed in NIO. Other geometrical tests recommended by TG142 may be performed with the system.
Results: The calculation model enables determination of isocenter with an accuracy of 0.05 mm. The diameter of the isocenter spheres for the accelerators installed at the NIO did not exceed 0.75 mm. The changes in the location of the therapeutic table had the greatest impact on the isocenter sphere diameter. The measurement time of accelerator's isocenter is shorter than 20 minutes. The longest part of measurements is the external calibration.

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OPTIMIZATION IN RADIOTHERAPY INTEGRATING A MULTIDISCIPLINARY FRAMEWORK WITH GEANT4

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Purpose: Radiotherapy treatment (RT) is one of the most important cancer treatments; mathematically, it is a constrained multi-objective optimization problem.

In RT, a prescribed dose is delivered to the target tissue to minimize the risks of radiation-induced complications. The solution to the problem appears simple, but achieving the best radiotherapy plan for a specific patient is a difficult challenge.
Our aim is to introduce the knowledge of optimization techniques from other engineering fields into medical physics to optimize a treatment plan.
Material and methods: GEANT4 and modeFRONTIER have both been used to optimize a RT plan. modeFRONTIER is an integration platform for multi-objective and multi-disciplinary optimization, developed by ESTECO, an independent Italian software company highly specialized in numerical optimization, simulation process, and data management. It provides a seamless coupling with third-part engineering tools, enables the automation of the design process simulation, and facilitates analytic decision-making.
GEANT4 is an open-source Monte Carlo (MC) simulation toolkit for precise dose calculation. MC algorithms are more accurate than conventional techniques. They reduce uncertainty in dose calculation and the uncertainty in overall delivered dose.
We created models for patient and medical linac based on the medical_linac example models in the GEANT4 distribution. The optimization was executed using the MOGA-II algorithm. The objective was to find the linac parameters that would maximize the tumor dose while minimizing the related side effects.
Results: The coupling of modeFRONTIER and GEANT4 worked well; we were able to find the optimal configuration with a reduced number of initial particles in the MC simulation.
The results were analyzed using the global γ-index 3%/3mm, and the test passing rate for all distributions was greater than 95%.
By utilizing a simplified TPS model, we retrieved the best configurations for tumor treatment. MOGA-II explored an area in the objective space not accessible in the initial designs. It also found a homogeneous Pareto front, with optimal designs distributed throughout the whole region.
Conclusions: Medical physics benefits from the expertise in optimization derived from other engineering fields. Our procedure can be applied to optimize some linac components, such as the electron source.
RT plans benefit from the usage of MC algorithms, indeed they are more accurate than the conventional techniques and are suitable for a personalized treatment plan.
With its state-of-the-art algorithms for optimization, sensitivity analysis, and uncertainty quantification, modeFRONTIER is also a helpful tool for managing uncertainties in radiotherapy.

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MONTE CARLO AND RAY TRACING DOSIMETRIC CHALLENGES FOR CYBERKINFE ULTRA-SMALL CRANIAL TARGETS

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Purpose: Dose calculations accuracy in treatment planning systems are of crucial importance for the outcome of radiotherapy. Literature shows that Ray-Tracing (RT) and Monte Carlo (MC) algorithms are relatively equivalent in homogeneous regions within 4% dose deviation for most tumor sizes down to 1.5cc. There is however very little literature on ultra-small targets less than 0.05cc . In this work, dosimetric changes between the RT and MC algorithms for tiny Trigeminal Neuralgia (TGN) (typically 0.05cc) were analysed and compared.
Materials and methods: Accuray's Multiplan treatment planning system version 4.6 was used in this study .All patients had been previously treated on HMC's Cyberknife (CK) using RT algorithm. Multiplan provides the option of using either the RT or the MC algorithm for the final dose calculation. RT calculated plans were re-calculated using the MC algorithm maintaining the same MU and beam arrangements. ICRU_91 metrics were used to quantify the dosimetric plan changes seen when using the two algorithms. The following dose metrics were recorded for all treatment plans: TGN volume, cone size, max_pixel, min_pixel, Dnear_max, Dnear_min, median_dose(D50), Gradient index(GI50), Conformity Index(CI), and heterogeneity indices HI. In addition the Brain and Brain Stem max doses were compared for both algorithms.
Results: The Recalculated MC plans showed some interesting differences when compared to the original RT calculated plans despite the treatment site being homogenous. 25 patient plans were randomly selected for this study. The average TGN volume was (0.045cc) while the most common cone size used for treatment was 5mm in diameter. The average TGN prescription change was (38cGy). The average TGN coverage change was (0.001%), average TGN min_pixel change was (3.84%). Average TGN max_pixel change was (1.89%). Average TGN Dnear_max change was (0.46%). Average TGN Dnear_min change was (22.46%). Average TGN median_dose change was (2.03%). Average TGN Gradient_ index change was (17.71%). Average TGN Conformity_ index change was (9.59%). Average TGN heterogeneity_ index change was (2.02%). Average TGN brain dose (volume of 12Gy) change was (8.04%). The brain dose max pixel dose average change is 10.03%.
Conclusion: For ultra-small targets CK-based radiosurgery, the RT calculation may overestimate the target dose and underestimate the dose to the OAR's. In addition, RT calculated plans overestimate the dose falloff giving a significantly lower GI50 than the MC calculated plans.

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AUTOMATION OF PENCIL BEAM SCANNING PROTON TREATMENT PLANNING FOR INTRACRANIAL TUMOURS

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Purpose: Evaluate the clinical feasibility of a comprehensive automation system for proton treatment planning of intra-cranial tumours.
Material and methods: Ten patients have been employed for evaluation of the automatic selection of the beams' geometry. A script has been implemented in RayStation treatment planning system (RS) using Python code, allowing the user to identify automatically the target position and suggest predefined beams setup named as Class solution (CS) or explore angles close to CS called automatic CS (aCS). aCS automatically explores, based on the gantry range and gantry angle step defined by the user, all possible beams' geometries, considering as a starting point the one provided by the CS and providing a correspondent number of aCS. Each aCS beam is ranked based on standard deviation of the Hounsfield Unit (HUsd) distribution along each beam path. The same ten patients have been enrolled to training a home-made script algorithm implemented in RS. The script (named GPS), optimize plan dose combining two methods: computation of a benchmark dose as starting point and a wish-list approach. An independent cohort of 10 patients has been then employed for the evaluation of GPS. Time and dosimetric differences, based on clinical constraints, have been

compared between the manual and the GPS plans, also considering the CS and aCS beams' geometry setup.
Results: Target localization performed accurately in 100% of the cases. An average of 22 minutes is required for beams' geometry selection (range 9-29 minutes). On the other hand, the average time for the GPS optimization is 18 minutes (range 7-26 minutes). Median dose differences (GPS-manual) for each OAR are: brainstem -1.60Gy, left cochlea -1.22Gy, right cochlea -1.42Gy, TCS 0.13 Gy, left eye 0.55Gy, right eye -2.33 Gy, optic chiasm -1.87Gy, left optic nerve -4.45Gy, right optic nerve -2.48Gy and back optic path -0.31Gy. In 77% of the cases, OARs' constraints are within tolerance both in the manual and automatic plan. Manual plans, if compared with CS and aCS plans, show lower HUsd in the 60% of the cases, with a mean HUsd difference of -25.9HU and 7.7HU respectively (aCS performs better). Dosimetric CS and aCS evaluation shows a slightly worsening of the OARs values except for the left eye for aCS, the back optic path and optic chiasm for both CS and aCS.
Conclusion: This study has shown the feasibility of a comprehensive proton automatic planning system for intracranial tumours, already available for clinical implementation.

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A STUDY OF A TECHNICAL PROTOCOL FOR NON-REFERENCE DOSIMETRY CONDITIONS IN RADIOTHERAPY

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Purpose: The Italian Association of Medical Physics (AIFM) in cooperation with the Italian National Institute of Ionizing Radiation Metrology (ENEA-INMRI) offers a certified audit service to radiotherapy centres for reference dosimetry in photon beams. Meanwhile, a study is ongoing to extend the audit service in non-reference dosimetry. Here we report on the first step of this study.
Materials and methods: For 6 MV photon beam, the absorbed dose is measured in a cylindrical water phantom. Three different configurations are examined:
a) 4 box fields 10 cm×10 cm at different angles (0°, 90°,180° and 270°) to delivery an uniform dose in the target volume;
b) 360° dynamic conformal arc shaped on target volume;
c) a VMAT (Volumetric Modulated Arc Therapy) treatment plan with 4 arcs.

The target volume in condition a) and b) is a sphere of 6 cm diameter. The VMAT plan simulated a Simultaneous Integrated Boost head-neck treatment for two target volumes with two different dose prescriptions and several Organs at Risk with proper dose constraints. The Total number of Control Points was 256 and the number of monitor units was equal to 913 MU.
In all conditions, the planned dose in target volume is 2 Gy. Thermoluminescent dosimeters (TLD), assembled in a waterproof PMMA holder, are applied to measure the delivered dose.
TLD measurement accuracy is evaluated by comparison to a reference Farmer ionization chamber in the irradiation condition a) and b).
Results: Ionization chamber measurements show that planned and delivered absorbed dose in conditions a) and b) agree within 0.6%. In the same conditions the agreement between TLD and ionization chamber measurements is around 0.6% that is well within the TLD measurement uncertainty. In the VMAT plan, the percentage difference between TLD measured dose and TPS dose evaluation is up to 6%.
Conclusions: The comparison with the ionization chamber shows that our TLD dosimeters are suitable for dose measurements in a set of non-reference conditions. Future measurement will be planned to investigate the significant dose difference obtained for the VMAT plan.

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INCREASED ACCURACY IN DOSIMETRY FOR SMALL FIELD RADIATION FIELDS IN PRESENCE OF MAGNETIC FIELDS

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Purpose: Modern radiotherapy uses extensively small radiation fields in clinical treatments. The calibration coefficient of detectors in small radiation fields (<3x3 cm2) deviates from the coefficient in the 10x10 cm2 reference field. This deviation increases towards smaller fields. Treatments based on MR linacs requires dosimetry in the presence of a magnetic field (B), which has a big impact on the detector calibration coefficient in reference radiation fields and depends on orientation and magnitude of B. Therefore, the combined effect of small radiation fields and B on detector calibration coefficients needs further research and is the purpose of this study.
Material and methods: Two detectors for small field dosimetry with clearly different characteristics (one solid state detector (PTW 60019) and one ionization chamber (PTW 31022)) were selected. Geometrical models of these detectors have been developed and included in a phantom, mimicking clinical measurement conditions. Based on these geometries Monte Carlo (PENELOPE) simulations have been carried out to calculate the detector calibration coefficients as a function of radiation field size, S. These detector calibration coefficients were normalized to the calculated calibration coefficient for the reference field, both with and without magnetic field (|B|=1.5 T) present. For each detector a linear function was fitted to the normalized detector calibration coefficients to parametrize the correction factor, k, as function of S.
With both detector types, measurements on the central beam axis in a clinical MR-linac have been carried out for square radiation fields with, S, down to 0.5 cm and for the reference field (S=10 cm). These readings were corrected with k(S). S of the radiation fields was determined by cross profile measurements.
Results: The largest deviation of k(S) from 1 was found for S=0.5 cm and the PTW 60019 detector with a value for k(S) of 0.939 (±1.2%). The value of k(S) for the same field and the PTW 31022 was 1.018 (±0.5%). Comparing the uncorrected measurements results of both detectors for the same field shows a maximum differences of 6.7%, which reduces to maximum 2.0% after correction of the measurement with k(S).
Conclusion: Calibration coefficients of detectors for small field dosimetry are strongly affected by the magnetic field when used for small field dosimetry in MR linacs. An independent method to correct for this has been developed and demonstrated to yield accurate and clinically acceptable results.

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INVESTIGATION OF SUITABLE DETECTION ANGLES FOR CARBON-ION RADIOTHERAPY MONITORING USING CHARGED NUCLEAR FRAGMENTS

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Purpose: Carbon-Ion Radiotherapy (CIRT) allows the delivery of a highly conformal dose distribution while minimizing the irradiation of organs-at-risk. However, CIRT is sensitive to treatment uncertainties, which might lead to changes in the dose distribution. Thus, it is desired to monitor the beam delivery within the patient. Our research group has been investigating in-vivo and real-time monitoring methods based on tracking of nuclear charged fragments emerging from irradiated patients. This research is based on a mini-tracker composed of two hybrid semiconductor pixel detectors (Timepix3). Performance of the monitoring depends on the detector position. Therefore, in this work we investigated suitable detection angles of the mini-tracker relative to the beam axis to detect and localize a small air cavity of 2 mm thickness. The air cavity represents an anatomical change in the tumor volume.
Material and methods: Experiments were conducted at the Heidelberg Ion Beam Therapy Center (Germany). A homogeneous plastic head phantom was irradiated with one field of a clinic-like treatment plan with an RBE-weighted dose of 3 Gy (RBE). Fragment emission profiles were measured using a mini-tracker with a sensitive area of 2 cm^2. Two different positions of the air cavity along the beam axis were investigated.
Results: The accuracy of the air cavity localization was improved at larger detection angles, while the statistical significance air cavity detection was found to be increased at smaller detection angles.
Conclusions: The variation of the detection angle leads to a trade-off between the number of detected fragments and the achievable spatial resolution. Detection angles of 20° – 30° were found to be a good compromise for accessing both the detectability and the position of the air cavity along the beam axis.

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MEASUREMENTS OF OUTPUT FACTORS IN HELICAL TOMOTHERAPY DELIVERY

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Purpose: Tomotherapy is an advanced linac which is able to deliver helical treatments. Due to its peculiarity, dose measurements cannot be performed in standard conditions: new reference conditions were thus recently established by AAPM TRS 483. A consistent dataset to be used as reference for on-site measurements validation can be provided by harmonizing the expertise at different radiotherapy centers and encouraging data standardization. The aim of this work is to present the first phase of a pilot study where several Italian radiotherapy departments have been involved in common measurements of output factors of small fields in Tomotherapy units by using multiple detectors and phantoms. Measurements performed at the reference center of radiotherapy department of Careggi hospital in Florence are presented.
Methods: Measurements were performed both in water and solid phantom. Five detectors, Micro Diamond PTW (MD), A1SL Chamber (AC), Razor Chamber (RC), CC13 IBA Chamber (CC), Razor Diode (RD) were tested in measuring output factors for a set of apertures defined in X- direction by the MLC (1.25, 2.5, 3.75, 5 cm) and in the Y-direction by the jaws (1, 2.5, 5cm) for a total of 12 field sizes in a 3D water phantom (Blue Phantom Helix). Measurements with EBT3film (GAF), MD and AC were also performed in a solid water phantom at the same condition. Output factors were assessed at a reference 10x5 cm2 field size at 85 cm SSD and 10 cm depth. MD and CC values were corrected by table 24 from TRS 483. Deviations from GAF data were calculated.
Results: RD and MD results are in agreement with a maximum deviation from GAF values of 2%. RC, AC and CC show a maximum deviation of 5%, observed in a single dataset (Y-jaw1cm). Results obtained in solid water phantom are also in good agreement with deviations within 1% and 5% observed for MD and AC respectively.
Conclusion: Data show that both solid state detectors are suitable for output measurements in Tomotherapy. Ionization chambers present, especially for the smaller filed size, higher deviations, derived from physical effects of their active area bigger than solid state detectors. Moreover, the employ of a solid water phantom is particularly advantageous to assemble the measurement setup, that becomes easier without loss in data accuracy. Eventually, analyzing data collected by other centers involved in this project, correction factors for all detector (here investigated and not present in TRS 483 protocol), will be calculated.

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COMPARISON OF LINAC QA AUTOMATION SOFTWARES AND EXPERIERENCE IN COMMISSIONING

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Purpose: There are currently various softwares commercially-available to automate all sorts of Linac QA task, e.g. mechanical check, MLC check, image quality check etc, using acquired DICOM images. However, each software has its own approach of analyzing and user interface. In order to have a better understanding of three softwares, i.e. Doselab, TotalQA and Pylinac, this work presents fundamental usage of them and also clinical experience in commissioning these softwares.
Material and methods: All three softwares have the following module for evaluation: Multi-image Winston-Lutz test is used for iso-center verification; Imaging Module for CBCT and planar image quality check; MLC test with various gantry speed, dose rate and MLC leave speed; Field test for field size, flatness and symmetry. Same set of DICOM images were used for analyzing and result was compared. Data processing is presented for each software. The workflow and user interface for each software is compared for peer review. Lastly, experience in setting up of baseline for each test is reported.
Results: All three softwares have advantages. Pylinac is free to use but not as flexible as the other two softwares, which is also demanding extra programming skill. TotalQA is web-based so no download or installation is required. One other benefit is that daily QA results could be integrated in the same platform. Doselab is one software with most flexibility, allowing user to modify ROI area etc. They present different results because methodology and algorithm are discrepant. However, the key of routine QA is monitoring the

machine stability. Therefore, each software could be an assistant for working efficiency and accuracy.
Conclusions: Successful implementation and comparison between three automation Linac QA softwares have been presented. Even though the result for each test varies but as long as the test keeps consistent, each software could be utilized in clinical with reliability.

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SENSITIVITY OF RADCALC EPID DOSIMETRY FOR IN-VIVO COMPOSITE DOSE EVALUATION

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Purpose: This study is designed to test the sensitivity of the RadCalc EPID Dosimetry system using a heterogeneous Easy Cube phantom in a full body configuration, from LAP.
Material and methods: The RadCalc EPID Dosimetry system was commissioned for pre-treatment and in-vivo measurements.
The in- air measurements required approximately 20 minutes per energy. The in-vivo measurements were approximately 1 hour per energy. Six field sizes were used from 2 cm by 2 cm to 24 cm by 24cm. As well as 8 thicknesses incrementing by 5 cm from 5 cm to 35 cm taking the couch into account and including one delivery with nothing in the beam.
A treatment plan was created and delivered on the Elekta machine three times. 2 errors were introduced. First the plan was delivered with the wrong monitor units, and then it was delivered with he corrected Monitor Units. Both of these were delivered with the phantom flipped 180 degrees on the couch. The third time and second the phantom was aligned as intended.
Images were captured with the EPID during delivery and imported into RadCalc to compute the respective dose volumes.
We evaluate the dose volumes histograms for two structures using the heterogeneous Easy Cube phantom, the isodose lines and gamma analysis. A gamma threshold of 3% 2mm is used while ignoring values lower than 10% of the max dose.
Results: In this first calculation, the lateral monitor units were incorrect, here is the DVH with the incorrect monitor units and corresponding Gamma analysis of only 25.2% of voxels passing.
The second calculation has the correct monitor units delivered, the plan is recalculated, and the DVH comparison improves significantly. However, the sensitivity of the flipped phantom shows up as demonstrated by the DVH discrepancies and the unique areas of gamma failures, demonstrating issues in expected anatomical densities. Additionally, the pass rate is still below 90%
In the third calculation, the treatment was performed as intended and we see the DVH match very well and a gamma passing rate of 99.4%
Conclusions: This leads to a great result of the sensitivity of RadCalc's EPID Dosimetry System.
It helps illustrate that even If you have verified the plan was delivered as intended and the machine has done its job perfectly by using the log files, there is still a need to verify changes from the intended plan and patient setup and changes through treatment.

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KNOWLEDGE-BASED PLAN PREDICTION MODEL FOR PROSTATE SBRT DELIVERED WITH CYBERKNIFE ACCORDING TO THE RTOG0938 PROTOCOL

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Purpose: To extend the KB-approach using RapidPlan (RP) tool to SBRT with CyberKnife in the case of prostate treatment.
Materials and methods: Seventy-two prostate clinical plans of patients treated at our Institute with CyberKnife between 2017 and 2021 were exported from the CyberKnife system (Accuray Precision v 3.3) to Eclipse (Varian v. 13.6). All patients were treated according to the RTOG 0938 protocol, delivering 36.25 Gy in 5 fractions. Prescribed dose was normalized at the peripheral isodose (range 75%-84%). The clinical dose distributions were linked to a volumetric arc geometry (two complete arcs) to assess the association between the principal components (PC) of DVHs and the anatomy/geometry components. Bladder, rectum and femoral heads (right and left or paired) were considered in the DVH prediction model. Fifty-two randomly chosen plans were selected to train the KB-model using the Rapid Plan (RP) tool (Varian, Inc.) and the remaining 20 plans were used to validate it. Clinical DVHs were compared against the corresponding DVH band values predicted by the model, for selected dose-volume parameters, according to the RTOG protocol: V95%, V90%, V50% for the rectum and V90% and V50% for the bladder.
Results: The final KB-model consisted of 51 trained plans with 50 structures for the rectum, 48 for the bladder and 52 for the femoral heads. The final model resulted in a linear regression between real and estimated PC, with R2 equal to 0.70, 0.55 and 0.56 for rectum, bladder and femoral heads, respectively. When comparing clinical vs predicted DVHs, the clinical DVHs were generally within the lower and upper band values predicted by the model, both for internal and external validation cohorts. Of note, for the external cohort 6/20, 5/20 and 4/20 clinical plans were lower than the estimated DVH bands when considering V95%, V90% and V50% rectum dose-volume points, respectively. For the bladder, 3/20 and 3/20 clinical plans were lower than the estimated bands when considering V90% and V50% dose-volume points, respectively. However, for all cases, the estimated lower band was within the RTOG protocol constraints. Femoral heads predicted values were far below the dose-volume constraints.
Conclusions: The feasibility of building a robust KB-model for SBRT application with CyberKnife seems demonstrated. The translation of the model into an individually tailored template for automatic plan optimization is currently ongoing.

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AUTOMATIC COMMISSIONING OF AN ELECTRON BEAM MODEL FOR ELECTRON RADIOTHERAPY APPLICABLE TO PHOTON MLC SHAPED BEAMS

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Purpose: Currently, the commissioning of beam models for electron radiotherapy utilizing the photon MLC for beam shaping

is a manual and time-consuming process. In this work an automatic commissioning procedure for a Monte Carlo (MC) beam model is developed for TrueBeam systems with electron energies ranging from 6 to 22 MeV.

Material and methods: The considered electron beam model includes a main source representing the primary beam and a jaw source representing the head scatter contribution each consisting of an electron and a photon part. For the MLC MC radiation transport is performed. The automatic commissioning relies on pre-determined information from BEAMnrc simulations of the treatment unit, in-air profile and absolute dose measurements in water for different field sizes and source to surface distances (SSDs) with in total seven measurement scans. This information is used to determine the source parameters in the beam model such as the fluence distributions, source weights, energy spectra for all sources as well as the focal spot position and lateral intensity distribution for the main source. To validate the commissioned beam model, calculated and measured dose distributions in water were compared for different field sizes (2×2, 5×5, 10×10 cm2), SSDs (70 to 90 cm) and beam energies (6 to 22 MeV) for seven TrueBeam systems. In addition, a sternum case in an anthropomorphic phantom was considered using a 22 MeV photon-MLC shaped electron field and calculated and gafchromic film measured dose distributions were compared at different SSDs.

Results: The automatic commissioning procedure was successfully implemented and applied to seven TrueBeam systems. Instead of the manual commissioning taking up to several days of calculation time and several hours of user time, the auto-commissioning is carried out in minutes. Measured and calculated dose distributions in water agree generally within 3% of maximum dose or 2 mm. The gamma passing rates for the sternum case using 3% (global) and 2 mm criteria with a threshold of 10% ranged from 96% to 99%.

Conclusions: The newly developed automatic commissioning procedure allows an efficient commissioning of an MC electron beam model. The result of this work eases the usage of electron radiotherapy utilizing the photon MLC for electron beam shaping. This work was supported by Varian Medical Systems.

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KILOVOLTAGE RADIOTHERAPY TREATMENT PLANNING USING MONTE CARLO SIMULATIONS

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Purpose: Kilovoltage (kV) radiotherapy treatment planning is currently performed via manual water based Monitor Unit calculations. These have inherent limitations as they do not take into account the heterogeneity of tissues nor complex surface geometries in a patient. Lack of 3D dose distributions make it impossible to compare kV treatments to other modalities as well as to account for previous or future treatments from a dosimetric perspective. The aim of this work was to create and validate a Monte Carlo (MC) model of a kV treatment unit and to use the model to calculate 3D dose distributions on patient CT images for educational or clinical guidance purposes.

Materials and methods: EGSnrc MC package was used to create a model of xStrahl 200 Orthovoltage unit along with all clinically used applicator/energy combinations. The model was validated via watertank measurements of Percentage Depth Dose (PDD) curves and in-plane/cross-plane beam profiles at depths of 1cm, 5cm and 10cm using PTW MicroDiamond detector. Simulated beam spectra were used to calculate half-value layers (HVLs) for all clinical energies (70-200kV) and backscatter factors (BSFs) for all clinical applicators (2cm circle 20cm SSD – 20x20cm 50cm SSD). These were compared to measured HVLs and IPEM published BSFs used clinically.

A Python suite of interactive applications was created to accommodate clinical implementation of the project. These allowed modification of voxel HU values to account for lead cut-outs, conversion of DICOM CT images to DOSXYZnrc MC phantoms, and 3D treatment planning with creation of a DOSXYZnrc simulation input file . Python application suite also allows the user to generate a dose volume histogram to aid dosimetry analysis as well as exporting the 3D dose distribution as a DICOM dose file, which can be imported into a commercial treatment planning system, such as Eclipse, for a more thorough analysis and comparison to other modalities.

Results: Watertank PDDs and beam profiles agreed with measurements to within 2% for all curves. HVL agreement was within 0.5mm of attenuating material for all energies. BSF agreement was within 3% for all applicators. Python application successfully accommodated simulation setup as well as dose distribution analysis for several patient treatments.

Conclusion: Modern, Python based, software can accommodate in obtaining and analysing MC calculated 3D dose distributions for kV radiotherapy treatments. The educational benefits of this novel clinical tool include dosimetry in heterogeneous media and lateral dose spread for complex shaped beams.

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CLINICAL COMMISSIONING AND ACCEPTANCE OF THE MRIDIAN® LINAC WITH THE THALES 3D MR SCANNER

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Purpose: The market introduction of the MR-Linac technology supports the improvement of the patient care quality via the real time target imaging and online table adaptive treatments. The use of conventional water phantoms with ferromagnetic material becomes prohibited due to the presence of the static magnetic field within the MR-Linac. The radiotherapy department of the UZBrussel (UZB) commissioned a MRIdian® Linac in June 2021 and used the MR Compatible Water Phantom THALES 3D MR SCANNER from LAP to complete the clinical acceptance of their MR-Linac beam model.

Material and methods: The design of the THALES Water Phantom has been optimized to fit with the bore shape of the MRIdian® machine of ViewRay®. The MR-Certification of the system has been validated by an independent laboratory. The electro-motorization of the Water Phantom is patented. The THALES application software has been developed using the web-browser technology. A central database is deployed on the clinical sites to permit the data sharing between multiple users. The software offers guided and semi-automated measurement processes as well as dedicated analysis tools to analyze Flattening Filter Free (FFF) beams. Data collection containing Crosslines, Inlines, Diagonals and Percentage Depth Dose distributions (PDDs) have been carried out for different beam setting conditions, containing various field sizes, measurement depths or surface-to-skin distances (SSD). The agreement between the independently measured beam data and the Treatment Planning System expectations of the Treatment Planning System (TPS) of the ViewRay® system has been evaluated based on gamma evaluations performed on the different acquired datasets, for various applied field sizes and measurement depths. The Gamma index for typical 1%, 1mm, distance to dose (DTD) and distance to agreement (DTA), exhibit a success outcome greater than 95% for the different tested configurations.

Additional measurements focusing on off-axis beam deliveries have been carried out to further investigate the multileaf collimator (MLC) accuracy.
Results: The deviations between the measured data and the Treatment Planning System expectations were found to be well within the recommended Dosimetry standards.
Conclusion: The THALES 3D MR SCANNER solution appears as a precise, reliable, fast, and user-friendly solution to perform the beam model validation of the MRIdian® machine. The UZBrussel (UZB) radiotherapy group has further deployed an intensive Quality Assurance (QA) program involving the THALES Water Phantom for the yearly QA procedures.

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REDUCING PATIENT SPECIFIC QA FOR VMAT PLANS THROUGH TPS SCRIPTING

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Purpose: Volumetric modulated arc therapy (VMAT) is the most commonly used radiotherapy treatment technique. This is associated with complex delivery systems and significant hardware burden. Dose rate modulation, collimators movements and gantry rotation should be precisely synchronized. Pre-treatment patient specific quality assurance (PSQA) ensures the correctness of the delivery. However, PSQA demands a significant time allocation. We propose to extract quantitative metrics from the treatment plans to predict QA failures and potentially ease the need of machine time.
Material and methods: We retrospectively analyzed 200 normo-fractionated VMAT plans using 6MeV photons with flattening filter and two arc-fields per plan. The plans were prepared for two different TrueBeam (Varian Medical systems) linear accelerators (Millennium and HD MLCs). The PSQA was measured using portal dosimetry (PD). Gamma passing rates were evaluated per field with a 3%/1.5mm criterion. We developed an in-house software based on the Eclipse Scripting API (ESAPI) libraries to extract per-field complexity metrics. These included mechanical parameters such as the overall travel leafs (OTL), mean MLC opening (MMO), mean leaf velocity (MLV) and also modulation parameters such as index of modulation (IOM), converted aperture metrics (CAM) and small aperture score (SAS). We performed statistical analysis to correlate the metrics among each other and with the PSQA data.
Results: The mechanical metric that showed the most significant correlation ($r=0.89$, $p<0.001$) with PSQA was MMO. Analogously, the modulation metric with the strongest correlation was IOM ($r= 0.96$, $p=0.003$). Despite the lower Pearson correlation, MMO was superior in discriminating the need for PSQA. All the plans retrospectively analyzed for which MMO was above the 10th percentile had gamma passing rate > 95%. The same result can be achieved with a threshold set at the 20th percentile of the IOM.
Conclusions: We developed an in-house ESAPI software to predict QA failures of VMAT plans. Among the investigated metrics, we conclude that the mean MLC opening provides the best performance in discriminating plans requiring or not requiring PSQA measurements. The number of PSQA can be reduced by up to 90% while ensuring to maintain a gamma passing rate >95% for all plans.

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OVERALL SURVIVAL PREDICTION BY MODELLING TUMOR CELL INFILTRATION IN HIGH-GRADE GLIOMA PATIENTS

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Purpose: High-grade gliomas (HGGs) is a common type of malignant brain cancer showing median patient survival below 15 months with treatment. The tumor cell invasiveness into normal tissues is considered the main determinant of the poor patient prognosis. Histopathological studies have shown that considerable regions of tumor cell invasion may not be visible on diagnostic images and tumor cell visibility threshold equal to 8000 cells/mm^3 on T1-MRI images have been reported. Aim of this study was to develop a mathematical framework for the prediction of HGG cell invasion into normal tissues to assist the clinical target definition and exploit the obtained tumor infiltration maps to provide estimates of overall patient survival.
Material and methods: A dataset of 93 HGG cases from the BraTS 2020 challenge was analyzed. For each case T1-MRI images, gross target volume (GTV) segmentation, survival time, and resection status were available. A model describing the change of tumor cell concentration in time and accounting for cell proliferation and cell diffusion into nearby tissue was applied. Tumor growth and invasion were iteratively simulated starting from an initial number of tumor cells located in the GTV center-of-mass. The simulation was halted when the isocontour of 8000 cells/mm^3 completely encompassed the GTV. Tumor infiltration maps were produced and corresponding isocontours with different cell density were considered.
ROC curves were used to seek for correlations between patient overall survival (with median overall survival as the selected endpoint) and the volume corresponding to a selected isocontour. The ROC analysis was repeated for each isocontour with varying cell density and for the segmented GTV. Area-Under-the-Curve (AUC) values were used to determine the isocontour having the highest predictive power. The optimal cut-off volume, rendering the highest sensitivity and specificity, for each of the considered isocontours was used to divide the patients in two groups for a Kaplan-Meier survival analysis.
Results: The highest AUC value was obtained for the isocontour of 1000 cells/mm^3 and 2000 cells/mm^3, respectively, equal to 0.767 (p-value < 0.001). The GTV yielded an AUC of 0.726 (p-value < 0.001). The Kaplan-Meier survival analysis using the 1000 cells/mm^3 isocontour and the ROC optimal cut-off volume for patient group selection rendered a p-value < 0.0001.
Conclusions: The simulated tumor cell invasion is a stronger predictor of overall survival than the segmented GTV indicating the importance of using mathematical models for cell invasion to assist the definition of the target for HGGs patients.

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AN INVESTIGATION OF A RADIO-CHEMICAL MECHANISM FOR EXPLAINING THE EFFICACY OF MINI-BEAM AND MICRO-BEAM RADIOTHERAPY

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Purpose: This simulation study investigates the chemical mechanism to define a surrogate to the experimentally observed tumor control during micro- and mini-beam radiation therapy (MBRT). The study focused on proton-MBRT (pMBRT) and the model was then used also for photon-MBRT (xMBRT). The spatial distribution of ROS was investigated to develop a model interpreting the MBRT efficacy.
Materials and methods: The current work was based on Monte Carlo simulations and it provides a more in-depth analysis of previously published MBRT animal studies. The TRAX-CHEM Monte Carlo software developed at GSI was used to model the radical production and diffusion as a function of radiation dose. The simulations were based on the properties of the proton mini-beams reported in the literature. The spatial distributions of twelve different molecules and radicals were tracked over several orders of magnitude of their time evolution. We investigated whether the distribution of a radiation-induced molecule or a radical could be a surrogate to describe the biological effect. The specific mechanisms leading to cell damage were outside the scope of this work. The molecules and radicals were selected according to a set of properties: (i) they should be stable to allow diffusion achieving coverage of the dose-valleys, (ii) they should reach a steady state in production versus removal, (iii) they should be a product of water radiolysis, and (iv) they should have oxidizing capacity.
Results: The results show that hydrogen peroxide (H2O2) fulfills all the requirements. Moreover, the modeling of its temporal and spatial distributions demonstrate that a uniform coverage of the target by H2O2 can be achieved during the beam-on time. The model was compared and proven to be compatible with three independent photon micro-beam and proton mini-beam animal experiments.
Conclusions: We conclude that H2O2 is a good candidate to describe the mini-beam and micro-beam efficacy. Further experiments are proposed to experimentally benchmark the model and to correlate the hydrogen peroxide concentration to the tumor control probability.

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TREATMENT PLANNING RECONSTRUCTION FROM HODGKIN LYMPHOMA RADIOTHERAPY IN THE 1990S: A COMPARISON OF DOSE CALCULATION ALGORITHMS

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Purpose: Dose-response analysis of secondary neoplasm risk after childhood cancer radiotherapy requires retrospective organ dose reconstruction. This is particularly difficult for patients treated in earlier years when treatment planning was not based on 3D imaging. We used a phantom-based approach to estimate applied organ doses of paediatric patients treated for Hodgkin lymphoma within the HD-90 study in the 1990s.
Material and methods: Using the 3D-CTs of six artificial hybrid phantoms [1] (male and female with the age of 5, 10 and 15 years), we developed six standard treatment plans for each phantom based on the HD-90 study protocol. Thyroid, breast, lung, bladder, kidney, uterus and testes are particularly radiosensitive organs with elevated secondary neoplasm risk. Therefore, we estimated Dmax and Dmean for these organs for all treatment plans using the Analytical Anisotropic Algorithm (AAA), the Acuros-XB algorithm in Varian Eclipse, and a Monte-Carlo algorithm in PRIMO.
Results: Across treatment plans, the mean organ doses differ by 51.06±31.94% for the 10-year-old female phantom, and by 47.89±36.00% for the 10-year-old male phantom, on average. Across the age spectrum for the irradiation of the cervical and supraclavicular lymph nodes of the female phantoms, the organ doses differ most for the thyroid with Δ(MAXy-MINy)Dmean = 13.0%. Taking the cervical and supraclavicular lymph node irradiation of the 5-year-old phantoms, Dmax and Dmean vary up to 8.0% between males and females. The mean value of Dmax and Dmean at the analysed OARs for all target volumes and phantoms differ less than 5% between the Acuros-XB and Monte-Carlo algorithm compared to the AAA algorithm. Depending on the target volume location as well as on the individual phantom, the dose difference between the algorithms vary mostly up to 10%. In general, the data shows that algorithms disagree less for the OARs outside of the treatment field.
Conclusions: The calculation algorithm plays a minor role in retrospectively estimating OAR doses. The main variance of the estimated organ doses appears due to different target volumes in the HD-90 study as well as due to sex- and age-dependent anatomical differences of the phantoms. As a next step, the developed model will be verified using real patient data.
Reference:
[1] Lee et al. The UF family of reference hybrid phantoms for computational radiation dosimetry. Physics in Medicine and Biology, 55(2):339-363, 2010.

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A NOVEL MODEL FOR PROTON RBE FOR TREATMENT PLANNING EVALUATION AND OPTIMISATION

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Purpose: For proton therapy, a relative biological effectiveness (RBE) of 1.1 has broadly been applied clinically. However, due to observed unexpected toxicities near proton track ends, several models for proton RBE have been proposed for evaluating and/or optimizing the treatment plans. Dose averaged linear energy transfer (LETd) is the most commonly used radiation quality descriptor in these models, but the method for calculating the LETd is not always consistent, potentially impacting the corresponding estimated RBE value.
This study proposes a new phenomenological RBE model with other quantities than LETd as input variables and evaluates their performances for RBE predictions.
Methods: A phenomenological linear-quadratic based RBE model is proposed for fitting in vitro cell survival data with various beam quality quantities used as input variables as alternative to LET, such as $z^*2/\beta 2$, here called effective Q (Qeff) and Q.
Each quantity, including LET, is calculated using the dose and track averaging methods, while the scoring includes all secondaries, all protons or only primaries, using the SHIELD-HIT12A Monte Carlo particle transport code for the experimental set-ups of recent high-throughput in vitro cell survival studies for proton RBE. The goodness of fit of the newly introduced phenomenological RBE model is determined for each of the quantities and compared using a bootstrapping approach, for both linear and non-linear fits.
Results: Versions of Qeff and Q more accurately predicts RBE than LET, with the best non-linear and linear fit having a relative root-mean-square-error (RMSE) for RBE2 Gy ± one standard error

of 1.73±0.04 (Qeff, t, primary) and 2.76±0.07 (Qeff, d, primary), respectively. For LETd, protons, the corresponding best non-linear and linear fits had a relative RMSE of 2.24±0.06 and 3.33±0.08, respectively. Using Welch's t-test for comparing the calculated RMSE of RBE2 Gy resulted in two-tailed p-values of <0.002 for all Q and Qeff quantities compared to LETd, protons, indicating a statistically significantly better performance. The equation for calculating RBE with Qeff, d, primary based on a linear fit is:
https://ibb.co/ynn8d6b
Conclusion: Proton RBE values might be more accurately determined by using versions of Q or Qeff as beam quality descriptors for both linear and non-linear phenomenological LQ based RBE models.

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STUDY OF GOLD NANOPARTICLES AS THERANOSTIC RADIOSENSITIZIERS UNDER CLINICAL CONDITIONS

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Purpose: Determining key parameters and conditions needed for the implementation of gold nanoparticles (AuNP) as theranostic agents in radiotherapy under realistic clinical conditions, and study the radiosensitization under these conditions in terms of increased DNA damage in cell cultures.
Methods: AuNP as contrast agent were evaluated scanning solutions with different gold concentrations. Clinical computed tomography (CT) and mega-voltage cone-beam CT (MV-CBCT) IGRT beam were used while nanoparticles were placed inside anthropomorphic phantoms emulating the actual clinical context. Moreover, dose enhancement was studied virtualizing different AuNP concentrations within the planning target volume (PTV) of different cancer patients' datasets. Monte Carlo-based treatment planning was performed using EGSnrc-derived code to evaluate treatment improvements when nanoparticles were present. Finally, the biological impact of AuNP as radiosensitizers was evaluated by quantifying DNA damage. This was accomplished in irradiated breast cancer cell lines, treated with or without AuNP, and imaging three-dimensional γ-H2AX foci in super-resolution stimulated emission depletion (STED) confocal microscopy.
Results: Gold nanoparticles achieved noticeable contrast levels of ~50 Hounsfield Units in clinical CT starting from concentrations around 2 mg Au/mL. This concentration was not enough neither for contrast in MV-CBCT, nor for significant improvements in therapeutics in terms of dose enhancement. For these use cases, concentrations needed were one order of magnitude higher, achieving dose enhancements of around 15% while using clinically acceptable beams. Treatment improvements were obtained both in terms of dose-volume histograms and conformity in the PTV. Lastly, as theorized, an increase of DNA damage was detected and quantified at different doses in cells treated with AuNP when evaluating radiosensitization.
Conclusions: This work settles key parameters needed for a successful translation of AuNP to the clinical reality. In addition, it demonstrates and quantifies the radiosensitization mediated by AuNP in terms of biological damage to DNA.

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SYSTEM FOR 4D DOSE VERIFICATION AND MLC TRACKING TREATMENT PLANNING

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Purpose: Planning and verification for treatment of patients with moving lesions due to respiratory movement using novel 4-D modular system.
Methods: Development of modular system that allows 4D-CT imaging data analysis, treatment, and subsequent assurence and verification. Both hardware and software are integrated as part of the device. MATLAB-based, in-house developed software that allows video reconstruction and point-to-point exploration through every respiratory phase. Use of 4D region growing module, to set out a single "seed", in any respiratory phase, within the lesion boundaries. The software then propagates the search throughout all phases, producing the corresponding lesion volume found in each phase. Follows a group of optimizing software modules that calculate a PTV treatment sequence. These PTVs are calculated by projecting in the correct order the phase-volumes from all gantry angles POVs. Based on LINAC and MLC specs the optimizers identify the optimal starting points that allow the gantry and MLC to follow the lesion and continuously adapt to it's changing morphology and position. Time, and spatial coordinates from the region growing, will allow an ionizing radiation detector, supported by the hardware, to replicate with precision the movement of the lesion. The data gathered from irradiating the detector during the replicated movement in a particular PTV sequence is then compared with a full Monte Carlo simulation for verification purposes.
Results: The segmented volumes, when compared with their clinical hand-drawn counterparts show impressive similarities. After optimization, multiple PTV sequences are appropriate for treatment. Usually the more favorable is the PTV sequence that covers multiple phases which contributes to an homogeneous dose distribution. By moving the part that houses the detector (ion chamber, pin point, diode, etc), the device's hardware is able to move it faultlessly, replicating the lesion movement through a phantom. Any double open end phantom can be used with the device. Many add-on parts (eg harm for respiratory belt synchronized movement) provided extra synergy and control points.
Conclusion: The developed system can help to a safe and efficient clinical implementation of MLC tracking in radiotherapy by means of a manageable dynamic dose measurement, which is able to follow the lesion movement recorded in the clinical image. Also any other control point tracking, for 4D dose distribution verification, is possible using the device.

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DOSIMETRIC ROBUSTNESS OF LUNG TUMOR PHOTON RADIOTHERAPY EVALUATED FROM MULTIPLE EVENT CT IMAGING

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Purpose: Intrafraction respiratory motion is a concern for lung tumor radiotherapy but full evaluation of its impact is hampered by

the lack of images representing the true motion. This study presents a novel evaluation using free-breathing images acquired over realistic treatment times to study the dosimetric impact in photon radiotherapy of respiratory motion not fully covered by 4DCT.

Material and methods: Cine-CT images for 14 patients with lung cancer acquired during 8 minutes of free-breathing at three different occasions were used with image registration to create sets of evaluation images. Unlike the cine-CT these evaluation images were large enough for dose computations and were used to enable simulated dose tracking for four different planning methods. According to recent trends in lung tumor photon prescription these methods all aimed to deliver a dose of 54 Gy in three fractions to D50 of the target and were denoted as robust 4D (RB4), homogeneous fluence (FLU) to the ITV and an isodose prescription to the ITV with a high central dose (ISD), concurrently renormalized (IRN).

Differences in dose coverage probability and homogeneity between the methods were evaluated and correlations between dose degradation and patient and motion attributes were investigated.

Results: For all prescription methods but IRN at least 93% of the patients would have received 95% of the intended dose.

All methods but FLU lead to achieving the intended CTV D50 with only a minor risk for underdosage in half of the patients.

No differences in D50 were found between RB4 and ISD nor IRN, however, RB4 had better homogeneity.

Conclusions: Robust 4D is recommended for planning of free-breathing treatments. Tumor motion in free-breathing not covered by the 4DCT had a small impact on dose. No factor was found that consistently correlated dose degradation with patient or motion attributes.

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AUTOMATED TREATMENT PLANNING FOR DOSE PAINTING BASED ON PET IMAGING

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Purpose: This work presents an automated strategy for dose painting (DP) treatment planning (TP). This strategy combines information extracted from hypoxia PET imaging and FDG-PET imaging for dose prescription and for post-optimization radiobiological outcome estimation.

Material and methods: Treatment plans were computed through a TP workflow assisted via scripting in RayStation. The automated pipeline comprised four steps:

Dose prescription: Dose modifying factors (DMF) to counteract radio-resistance were derived from normalized uptake of a PET tracer dedicated to hypoxia (FMISO). Clonogenic cell number (CCN) distribution was derived from FDG-PET. The DP strategy used DMF and CCN aiming at 95% tumour control probability (TCP) in the CTV. Dose prescription levels were assigned to segmented volumes.

Plan optimization: The optimization process was divided in two stages: A) Pre-optimization: the algebra combinations of the volumes of interest were performed. Disease-site objective functions, relative weighting factors, goals and its priorities were a priori set. B) The optimization phases:1) two optimizations prioritizing targets; 2) re-optimization of 1) but the dose to organs at risk (OAR) is reduced to meet the goals; 3) two minimax robust optimizations that mimicked both the OAR doses retrieved from (2) and the prescribed doses to targets.

Plan Evaluation: The nominal plan was checked according to priorities of the goals. TCPs were calculated by considering the underlying radio-sensitivity and CCN derived from the PET images in the initial stage.

TP Report: Optimized nominal plans were reported for further evaluation with respect to clinical acceptance.

Results: The functionality of the method for automated planning was tested on a selection of Head and Neck tumour cases, imaged with FDG and FMISO (as hypoxia tracer), and presenting different degrees of planning complexity. Photon treatment plans were automatically generated with the following specifications: total dose delivered in 35 fractions with integrated boost in the hypoxic volume and minimax robust optimization considering ±3mm setup errors. The 83% of obtained plans successfully met the clinical goals for spinal cord, brainstem and mandible. The average time for the automated TP workflow was < 40 minutes.

Conclusions: An automated TP workflow for DP accounting for the clonogenic cells and tumour hypoxia that could be implemented through scripting into the TP system was developed. The TP was positively tested for feasibility and it could be extended to different sites and treatment modalities supported by the TP system.

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PRELIMINARY STUDY OF BEAM MODEL-BASED COMMISSIONING: A SMALL FIELD EVALUATION

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Purpose and objective: Commissioning measurements are time-consuming and require high precision in execution. Reference Beam Models (RBM) consist of predefined Pencil Beam and Monte Carlo dose profiles that may dramatically reduce the number of measurements necessary to commission a beam. The purpose of this work was to evaluate the accuracy and robustness of using the RBMs offered by BrainLab®(Munich, Germany) with the treatment planning system (TPS) Elements® for multiple brain metastases.

Materials and method: The 6MV and 10MVFFF beams of a TrueBeamSTX Linac were considered. The Linac was equipped with a HD120 MultiLeafCollimator (MLC) whose central leaves have a width of 2.5mm at isocenter.

A Beamscan water tank (PTW, Freiburg, Germany) was used with a SSD=900. Absolute dose was measured at isocenter with a Farmer-type calibrated ion chamber for a 10x10cm2 field. Profiles and PDDs were measured for 4 different MLC-defined square fields ranging from 5x5 to 220x220mm2. Output Factors were measured for the same fields and in the same set-up. A PTW MicroDiamond detector and a 0.125cc PTW Semiflex 3D ion chamber were used for all measurements. A comparison between these measurements and calculations performed in a virtual water phantom with MC-Elements and Acuros algorithms were performed.

Once the TPS was configured, some "simple" plans (i.e. without MLC) and 5 patients were planned with the Multiple Brain Metastases module and delivered. The dose distribution was verified with three different methods. The 2D fluence distribution was evaluated with Portal Dosimetry. The log-file reconstructed 3D dose distribution was evaluated with an indipendent algorithm (M3D, Mobius). The measured 3D dose distribution was evaluated with the octavius detector.

Results: The total time required for the commissioning measurements was less than 6 hours. The best agreement between measured and modeled values both for OFs and profiles was obtained selecting a spot size of 0.4mm and 0.6mm for 6MV and 10MVFFF beams respectively (figure 1). Calculated OFs were within 1.6% for all field sizes except for the 5x5mm were it was 4.8% (figure

2). The 3%-3mm 3DGamma >96.3% (96.3%-99.8%) for the "simple" plans. Gamma values for the 5 clinical plans were 99.5%-100% for Portal Dosimetry, 99.8%-100% for the M3D calculation and 97.3%-99.1% for the Octavius4D measurements.

Conclusion: Machine commissioning times are dramatically reduced and compatible with clinical practice. The configuration and selection of the RBM is simple and intuitive. Good agreement between measured and calculated dose distributions was observed down to very small field sizes.

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DETECTION OF UNROBUST VMAT-BREAST TREATMENT PLANS USING STATISTICAL PROCESS CONTROL SPC APPLIED TO COMPLEXITY METRICS

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Purpose: To increase the overall quality of treatment plans in radiation therapy plan complexity and plan robustness need to be evaluated. In this study, statistical process control (SPC) was applied on multiple complexity metrics and the robustness evaluation of the plans out of control was carried out. This study aims to detect unrobust mamma treatment plans using SPC and evaluate their robustness regarding the setup uncertainties.

Material and methods: A total of 107 VMAT-Breast treatment plans were calculated in RayStation v.10A (RaySearch Laboratories, Stockholm) were evaluated. These plans include only-breast(n=69), Breast+LAW (lymph nodes)(n=26) and breast+LAW+SIB(n=10) and breast+SIB(n=1). Ten complexity metrics: Plan normalized MU (PMU), Plan averaged beam irregularity (PI), Plan averaged beam modulation (PM), Mean Field Area (MFA), Circumference/Area (CoA), Leaf travel (LT), Modulation Complexity Score (MCS), LTMCS (LT_PlanxMCS_Plan), Small-Aperture-Score (criteria=10mm) were calculated for all the treatment plans with a script. Afterward, SPC was applied to all the metrics by calculating the central line, upper and lower limit. A robustness evaluation of the setup uncertainties of the plans outside the limits of the SPC were conducted. The estimated setup uncertainties were based on the daily cone-beam computer tomography (CBCT) shifts of the patients. In some cases, as the treatment was delivered in deep inspiration breath-hold (DIBH), monitored via surface-guided (SGRT), the setup correction was applied based on the SGRT information. Finally, the worst-case scenario was compared to the nominal plan.

Results: Four treatment plans were outside the limits. One Plan was out of order in three different plan complexity metrics (PA, MFA, and LTMSC). Although the majority of the plans were only breast radiation, mostly Mamma with LAW (75%) were out of control. Indicating more complex plans than ordinary mamma plans. A comparison of the worst-case scenario to the nominal plan showed a decrease of approximately 8% for the dose coverage, 7% for the homogeneity index, and 12% for the conformity index. The heart dose and ipsilateral lung receive a higher dose in the worst-case scenario.

Conclusion: The result of the robust evaluation proves not correcting setup error with CBCT or surface-guided-system before radiation can lead to an underdose of the CTV while the organ-at-risks receive a higher dose as planned. The correlation analysis between the different complexity metrics is ongoing. The script created to accomplish this study has the potential to support planning process and plan selections through the evaluation of the delivered dose distribution.

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IMPACT OF ITERATIVE CT RECONSTRUCTION ALGORITHM ON THORACIC AND PELVIC RADIOTHERAPY PLANS DOSE CALCULATION

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Purpose: Recently, the Siemens Biograph mCT 64 PET/CT of Radiotherapy and Nuclear Medicine Department of our Institution was updated with CT iterative reconstruction method (SAFIRE). The aim of this study was to assess the reliability of the optimized CT protocols using iterative reconstruction method for radiotherapy simulation in thoracic and pelvic regions.

Material and methods: A CIRS Dynamic Thorax Motion Phantom (stationary scanned) and a Fluke CT Dose body phantom were employed to simulate thoracic and pelvic regions, respectively. The previously optimized protocols for thorax/pelvis have Quality Reference mAs values equal to 200/250 mAs and 120/160 mAs for FBP and Safire (strength 2) reconstructions, respectively, CARE Dose4D automatic X-ray tube current modulation and 120 kV for both protocols. In the thoracic region, three VMAT plans were optimized (using clinical templates and OAR constrains) simulating two lung lesions (48 Gy, 8 fractions, 6MV FFF; 40 Gy, 16 fractions, 6MV FFF) and a spinal metastasis (30 Gy, 10 fractions, 6MV FF). In the pelvic region, three different VMAT plans were calculated (prostate/seminal vesicles, 75.9/60 Gy, 30 fractions, 6MV FF; one lymph node metastasis, 42 Gy, 6 fractions, 6MV FFF; anal canal/lymph nodes 55/45 Gy, 25 fractions, 6MV FFF). The plans were recalculated on both FBP- full dose images (considered as reference) and on SAFIRE-low dose images (considering the two set of images as QA phantoms) using same dose voxel size (0.2 cm3) and Monte Carlo statistical uncertainty (0.5% per calculation) with Elekta Monaco TPS. Dose distributions computed on FBP and SAFIRE images were compared by global and local 3D gamma-index values (1%-1mm; considering points inside the phantoms with dose >10% of the maximum dose) with 3D Slicer Software (v. 4.11.20210226). CTDIvol values of FBP-full dose and SAFIRE-low dose scans were compared to assess dose sparing when using the iterative reconstruction method.

Results: In the thorax region, 99.9%±0.1%/98.3%±0.9% of points passes the global/local gamma analysis test while in the pelvic region the corresponding results were 99.7%±0.4%/97.4%±1.0%. The CTDIvol values for FBP-full dose/SAFIRE-low dose scans were 5.61 mGy/3.42 mGy in the thorax (CIRS thorax phantom) and 13.70 mGy/8.86 mGy in the pelvis (CTDI body phantom) resulting in 39% and 35% of dose saving when using SAFIRE CT protocols, respectively.

Conclusions: SAFIRE CT iterative reconstruction method can be used in planning CT protocols allowing for considerable patient dose sparing with comparable dosimetric accuracy to FBP-full dose protocols.

EPOSTER ABSTRACTS – AI

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SEMI-AUTOMATED AI BASED ORGAN DELINEATION ON LOW DOSE CT TO FACILITATE PET RADIOTRACER BIODISTRIBUTION MEASUREMENTS

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Background: Assessing PET radiotracer biodistributions, e.g. to study drug delivery and/or for dosimetry purposes, requires delineation of organs. Manual delineation is cumbersome, taking up to 8 hours per scan. We developed and evaluated an artificial intelligence (AI) based (semi-)automated organ delineation method using low dose CT images (from PET/CT studies).
Methods: The AI method consisted of three 2D U-net shaped convolutional neural networks (CNNs), one CNN for each slice orientation (axial, coronal, sagittal). The CNNs were trained using low dose CT images from 30 lung cancer and/or lymphoma FDG PET/CT studies as input images and organs delineated manually as labels (brain, lungs, liver, spleen, kidneys, bladder). Results from each trained CNN were combined using a majority vote approach to obtain the final organ segmentation. The AI method was externally tested using a test-retest FDG PET/CT dataset (n=10 cases, i.e. 20 scans). The quality of the AI generated organ delineations were visually evaluated, time needed to correct them reviewed and the repeatability of the segmentations was assessed by ICCs.
Results: The AI generated organ delineations were scored as excellent (almost no correction needed) for brain and lungs, good (minimal correction) for liver and spleen and moderate (up to 30 min to correct segmentations) for the kidneys and bladder. The overall time spent on organ delineation reduced from up to 8 hours for fully manual delineations to less than 30 min in most cases and 60 min for some difficult cases when using the AI based approach. ICCs for organ volumes were better than 0.97 for brain and lungs, 0.82 for liver, 0.70 for spleen and 0.80 for the kidneys. The lower ICC for spleen and kidneys (despite good visual quality of the organ delineations) most likely results from volumetric organ changes/displacements due to patient breathing and motion. Most challenging cases were seen in patients having large bulky tumors.
Conclusions: Use of our AI based method for (semi-) automated organ delineations on low dose CT greatly facilitates and provides huge time savings for the assessment of PET radiotracer biodistribution measurements. The method will be used as pre-segmentation of organs in radiopharmaceutical dosimetry and drug development (radiolabeled drugs) studies and is fully integrated in our in-house developed PET/CT biodistribution measurement and visualization tool. Other organs, such as bone marrow and (dense) bone, are currently delineated using HU values and morphological operators but will be incorporated within the AI method in the near future.

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EVALUATING THE FEASIBILITY OF USING DEEP LEARNING MODELS FOR SYNTHETIC IMAGE GENERATION IN ADAPTIVE RADIOTHERAPY

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Deep learning generative adversarial networks (GANs) have enabled image-to-image translation across multiple modalities. We investigated the application of GANs in two clinical cases: Cone Beam Computed Tomography (CBCT) to CT translation and synthesis of HX4-PET from FDG-PET.
For the CBCT to CT translation we used two cohorts from two different institutions: 259 CTs and 786 CBCTs of lung patients receiving proton therapy, and 192 CTs and 1576 CBCTs of cervix patients receiving photon therapy.
For the synthesis of HX4-PET images we used FDG/HX4-PET and CTs data of 34 patients from the PET-BOOST and Nitroglycerine trials.
Different GANs models were investigated for both the cases including paired/unpaired approaches, 2D vs 3D, different patching techniques, as well as 3 different GAN architectures.
The results were evaluated both in terms of quantitative metrics such as the MSE (Mean squared error), MAE (Mean Absolute error), SSIM (Structural Similarity Index Measurement), as well as by visual inspection of the synthetic images versus the original ones to spot the presence of artefacts. For the CBCT to CT data a gamma analysis was performed to investigate the suitability of synthetic CTs for dose recalculations.
For the HX4 study, the tumour and the hypoxia levels were segmented on the generated images and compared to the original values on the original images.
For the CBCT to CT translation experiments suggest that 3D models require significantly longer training time to converge but produce fewer perturbations in images than 2D models. Similarly, training with bigger patches rather than smaller improved stability and significantly reduced the number of artefacts. We extensively compared standard image similarity metrics (MAE, PSNR, SSIM) and visual evaluation of images, with the conclusion that the metrics do not reflect irregularities observed during visual evaluation. The best model produced a higher gamma pass rate than using a simpler calibration algorithm for the original CBCT.
Conversely, the HX4 study showed that a paired approach has better performances than the un-paired approach (best model in the CBCT to CT) when focusing on smaller regions (e.g., the tumour). However, when introducing in the unpaired model the support information of the CT, the results were comparable.
We have shown that it is possible to use deep learning to generate synthetic images of clinical relevance to be used for adaptive radiotherapy. However, the optimal configuration strongly depends on the intended use, and it provides different results when looking at larger or smaller anatomical structures.

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AN EXAMPLE OF PROSPECTIVE APPLICATION OF IMAGING BIOMARKER: SET-UP OF THE FIRST WORLDWIDE PROSPECTIVE PHASE III ONCO-HEMATOLOGICAL CLINICAL TRIAL USING TMTV FOR PATIENT STRATIFICATION

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Purpose: In the "Radiation-Free Therapy for the Initial treatment of Good prognosis early non-bulky Hodgkin lymphoma (HL)" (RAFTING) multicenter prospective phase 3 clinical trial, 160 non-bulky stage I-IIA HL patients will be enrolled in 5 European countries. Patient will be stratified into three risk categories according to baseline Total Metabolic Tumor Volume (TMTV) measured on PET/CT, modified EORTC criteria (mEORTC), and PET/CT response after 2 chemo-therapy cycles. Since it is, at our knowledge, the first time TMTV, as imaging biomarker, is used prospectively for patient management in clinical trial we set-up a stringent procedure for its reliable use.
Material and methods: Medical physicists from the participating site shall acquire two 18F-filled phantoms (the NEMA/ACR Image Quality Phantom - IQP and the Cylindrical Uniform Phantom CUP) and upload the reconstructed PET/CT images to Cuneo corelab. where image quality parameters are compared respect to the preset tolerance: difference between measured and expected activity concentration in CUP below 10% and recovery curve (RC) evaluated from IQP within EARL limits. All reconstruction algorithms available on PET/CT scanner (iterative, with resolution and/or noise modelling) shall be uploaded. If the tolerance are full-filled participating site could start to scan patients enrolled in the trial. Baseline PET/CT scan shall be uploaded to study website upon completion. To assure the maximum reliability in TMTV measurements tumor segmentation is independently performed by a panel of 4 reviewers using the same software. The TMTV value arising from the review is the average value if the their differences is below 10%. If it is not the case the segmented images are sent to Cuneo corelab for a lesion-based analysis that could require a consensus meeting among reviewers to resolve the differences.
Results: From June 2021 23/25(92%) PET/CT scanners fulfilled the CTQ. CTQ was reached at the first round in 90% of the cases (no interaction between the Cuneo Corelab and the local personnel regarding the data, phantom preparation, infrastructural problems). In the 3/21 patients enrolled at now (14%) a consensus meeting was necessary to solve the difference in TMTV evaluation.
Conclusions: the use of imaging biomarker in clinical trials requires an accurate implementation of the clinical protocol such as the one that we presented in RAFTING trial.

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SPATIAL RESAMPLING COMBINED WITH INTENSITY DISCRETIZATION IMPROVES REPRODUCIBILITY OF RADIOMIC FEATURES OF THE PAROTID GLAND

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Purpose: It is understood that prior to radiomic analyses, spatial resampling of CT images to an isotropic grid is required. This process is likely to influence the reproducibility of radiomic features (RF) used in predictive models; yet this has been overlooked in studies where the parotid gland (PG) is the region of interest. The aim of this study was to quantify the impact of spatial resampling on RF reproducibility within the PG. The reproducibility of RF values was also investigated under different fixed bin sizes used for intensity discretization in CT imaging.
Material and methods: CT images from a cohort of 127 patients with head and neck cancer were taken from the open access Cancer Imaging Archive, and the left PG was delineated by a single observer. Forty-two RFs were extracted using LIFEx software (v6.2) with the default bin size of 10. This process was then repeated following adjustment to a fixed bin size of 5. For both bin sizes, spatial resampling to an isotropic voxel size of 1x1x1mm^3 was performed. To assess the impact of voxel resampling on RF values, feature extraction was completed on the native CT image and again following spatial resampling. The difference in the mean values for each RF of the cohort following resampling was calculated, likewise for the difference in the standard deviation. Using these values, the absolute value of the percentage coefficient of variation (%COV) following resampling was calculated: $\%COV = |(\sigma/Mean) \times 100|$. The RFs were classified based on the influence spatial resampling had on the %COV for that feature. Class 1 were RFs where the %COV was <30%, Class 2 were RF where the %COV was >30% but <50%. Finally, Class 3 were RF whose %COV was >50%. This analysis was repeated for both bin sizes examined.
Results: Following spatial resampling, 58% (n=25) of RF extracted demonstrated consistent results regardless of either bin size used. Six features showed consistent poor reproducibility with a %COV>50% (NGLDM_Busyness, GLZLM_LZE, GLZLM_HGZE, GLZLM_LZLGE, GLZLM_LZHGE, GLZLM_ZLNU), and 10 showed consistently good reproducibility with a %COV<30% (HISTO_Skewness, SHAPE_Sphericity, SHAPE_Compacity, GLCM_Homogeneity, GLCM_Entropy_log10, GLCM_Entropy_log2, GLRLM_SRE, GLRLM_RP, GLZLM_SZE, GLZLM_ZP).
Conclusions: This work has demonstrated the impact spatial resampling has on RF values within the PG. A number of features which are reproducible under different fixed bin sizes have been identified. This work provides valuable information which may assist in the future generation of machine learning models for the prediction of xerostomia.

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AUTOMATED COMPUTED TOMOGRAPHY ARTEFACT DETECTION WITH DEEP LEARNING

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Purpose: Image artefacts encountered in computed tomography (CT) limit the diagnostic quality of the images and may result in a re-scan of the patient. CT artefacts exhibit characteristic features and thus, deep learning (DL) using convolutional neural networks has the potential to be applied for automated artefact detection. Subsequent monitoring of CT artefacts has applications not only for artefact detection but also in assessing the artefact prevalence of CT scanners. The purpose of this proof-of-concept study was to apply a deep learning classification framework for automated computed tomography (CT) artefact detection.
Materials and methods: Three CT artefacts (rotational patient movement, beam hardening, and ring artefacts (RAs)) and artefact free images were simulated with a custom python code using 2D axial CT slices (512×512 matrix) from an openly available Head CT data from John Hopkins University, containing 35 patients. For each slice image each artefact was simulated independently yielding total of four slice images. The simulated data was split into a training set (Ntrain = 1040×4(4160)), two validation sets (Nval1 =130×4(520) and Nval2 =130×4(520)), and a separate test set (Ntest = 201×4(804); two individual subjects). The VGG-16 model architecture pretrained with ImageNet dataset was used as the deep

learning classifier, and the Grad-CAM approach was used to produce attention maps for artefact localization. Model performance was evaluated using accuracy, average precision, area under the receiver characteristics operating (ROC) curve, precision, recall, and F1-score. Additional sensitivity analysis was performed for two test set slice images in which different RA radiuses (4 pixels to 245) and movement artefacts, i.e., head tilt with rotation angles (0.2° to 3°), were generated.

Results: The accuracy, average precision, and ROC area under curve for artefact detection over all classes were 0.91, 0.86, and 0.99, respectively for the test set. The precision, recall, and F1-scores were over 0.84, 0.71, and 0.85, respectively, for all class-wise cases. The additional sensitivity analysis revealed that the model could detect movement at all rotation angles, yet it failed to detect very small 4-pixel radius RAs.

Conclusions: Deep learning-based classification model can be used for the detection of simulated CT artefacts. DL-based detection could be applied in automated quality assurance and monitoring of the CT scan process for clinically measured CT datasets in the future. However, model performance verification using a clinical artefact dataset from a broader range of anatomical regions should be investigated in the future studies.

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SYNTHETIC PET IMAGING USING MULTI-PARAMETRIC MRI

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Objectives: the present work aims at predicting hypoxic condition in glioblastomas by means of synthetic 18F-FMISO PET when performing PET scan is not possible or inadvisable.

Methods: datasets from study ACRIN 6684 [1] were quality controlled and matching pairs of PET and MRI scans were co-registered to brain atlas [2]. After co-registration, deep neural networks were trained to infer synthetic PET images from anatomic and functional perfusion MRI scans using a regression loss function. Several models (UNET [3] vs OCM [4]) for fully convolutional networks involving different complexity and training input data sizes were considered. Similarity metrics were used to compare synthetic PET images with real PET images.

Results: training models with a single anatomical MRI channel already provided realistic synthetic PET images, with similarity metrics values close to those reported in the literature. Adding more anatomical or perfusion MRI channels provided limited benefit in our studies, possibly due to suboptimal co-registration of the multiparametric images. 3D models and patch based training appear to be promising techniques, especially for the resolution of hypoxic regions in the tumor area. Further, we could observe a different performance of complex UNET and OCM models (> 2×106 trainable parameters) trained with same noisy true PET images.

Conclusion: the work shows the feasibility to generate realistic synthetic PET images departing from anatomic MRI, while envisaging benefits in the joint use of anatomic and functional perfusion MRI data. By improving co-registration it is expected to see beneficial effects in training 2D and 3D models with smaller 2D and 3D patches. Further, in the context of noisy ground truth PET images, a better performance of 2D OCM over 2D UNET may be explained by the selective attention mechanism implemented by OCM. Such models concurrently assess context and details in the training data, in an attempt to emulate perception mechanisms of the human brain. Sub-optimal co-registration of PET to MRI data is a pitfall when dealing with multi-parametric data, as also is the shortage of standardized high quality 18F-FMISO PET scans to train the models.

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METAL ARTEFACT REDUCTION IN SPECTRAL PHOTON COUNTING COMPUTED TOMOGRAPHY USING DEEP LEARNING: A PROOF-OF-CONCEPT STUDY USING A BIOLOGICAL PHANTOM

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Purpose: Metal artefacts in computed tomography (CT) are caused by beam hardening phenomena and can manifest as bright streaks or dark bands originating from high-attenuating objects. Common ways of metal artefact reduction (MAR) include spectral filtration and computational correction methods. More recently, photon counting detector (PCD) technology and deep learning (DL) -based methods have been introduced for MAR. The purpose of this study was to combine these technological advances to assess their applicability in MAR using biological phantom samples.

Materials and methods: Chicken thigh samples (N=8) were fixed in a PMMA container using polyurethane foam and imaged with customized dual-energy PCD setup (120 kV, 10 keV noise floor threshold, 65 keV high energy threshold, 2 mmAl and 1 mmSn filtration, 120 mA, 720 projections). Full and 50% reduced dose scans were obtained with 0.48 mAs/projection and 0.24 mAs/projection. First scans were done without metal and subsequently metal inserts (N=1-4) were placed in the samples. The samples were re-scanned after each insertion.

Data were reconstructed with filtered backprojection (FBP, Ram-Lak filtering). Image stacks were limited to contain only the area with metal. The resulting dataset had 2420 slices and was split into training (2000), validation (100) and test sets (320, independent sample).

Two U-Net models were trained to predict metal-free images from images pre-corrected with linear interpolation (S_LI). First model improved sinogram inpainting in the metal trace using a training pair with two-channeled input {S_LI,S_metal; S_(non-metal)}, and the output S_(U-Net) was used to obtain:

S_corrected=(1-T)·S_metal+T·S_(U-Net),

where T corresponds to the metal trace in the image. After reconstruction, another U-Net was trained in reconstruction space using training pairs {FBP(S_corrected); FBP(S_(non-metal))}. Model training was experimented with conventional L_1 loss and a combination of L_1 and perceptual loss, using ImageNet pre-trained VGG-16 minimization schemes. Training was done over 10 epochs using Adam optimizer with LR=1e-4 (cosine annealing scheduler) and batch size four.

Results: U-Net based MAR substantially improved the image quality of the pre-processed metal images. When L_1 loss was

used in training, reconstructions appeared blurred due to tissue displacement around the titanium inserts, whereas perceptual loss was able to retain better sharpness.
Conclusions: This study demonstrates that a post-processing U-Net MAR implementation can reduce metal streaks in biological samples imaged with an experimental PCD setup. Combination of PCD technology and DL can be very effective in metal artefact reduction. Future research including validation with a more realistic anthropomorphic phantom model is required.

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A NOVEL APPROACH OF DENSITY-BASED CLUSTERING FOR COLOR AND FEATURE-BASED IMAGE SEGMENTATION FOR IMPROVING AUTOMATIC DETECTION IN MR AND CT IMAGES

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Purpose: In this study, a novel clustering algorithm is suggested to improve the image segmentation methods used in MR and CT images and reduce the errors involved.
Material and methods: To achieve the purpose of this study, a semi-supervised learning approach, more specifically, a density-based clustering method conditioned with general radiological supervision is proposed. In this approach, in order to extract different features from the image in question, three different convolutions are performed on the original image. Convolved images presenting the features along with the original image are then sorted into eight different 2-dimensional subspaces including the positions on one of the x or y axes and the grayscale values of each feature space so that each pixel can be represented as the following vector:
$P=\sum(fF+xX+yY)$
Where f is the value of each feature, and x and y indicate the location of the pixel in the original image.
Then the Voronoi diagram and the area of each division are calculated for each 2-dimensional subspace. The area representing each pixel is used for the classification. If an area is larger than a certain value, it is classified as noise, otherwise similar areas that can be spanned using a conditional minimum spanning tree (MST) will be classified as one group. The condition on the MST is the distance between the nodes at each step in question. Each of these classifications in each subspace will be traced back to the original image to form segmentations. In the last step, the overlapping sections of the primary segmentations combined with a weighted voting classifier will result in the final segmentation. Known radiological labels are then used as the semi-supervision to call back necessary conditions over the voting classifiers and conditional parameters to result in the correct segmentation.
Several sets of images from lung and brain tumors with and without labeled segmentations were collected and used for testing the proposed algorithm. Results were then compared with different clustering-based and non-clustering-based image segmentations. To evaluate the results, the standard deviation (SD) of the difference between each method and the labeled segmentation is calculated.
Results: The proposed method shows less or equal SD compared with other methods. Especially in the case of concave partitions, the proposed approach shows no error.
Conclusion: In case of a noisy image, low contrast, or when borders are not clear, this algorithm can be used for more accurate segmentation.

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EVALUATING THE EFFICIENCY GAIN IN USING ARTIFICIAL INTELLIGENCE BASED AUTOMATIC SEGMENTATION TOOLS IN RADIOTHERAPY TREATMENT PLANNING

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Purpose: Organs-at-risk contouring is a labor-intensive and time-consuming task of the treatment planning process. To speed up this task, an artificial intelligence powered automatic segmentation tools (AI tools) can be used. While all manufacturers follow consensus guidelines, each model is trained on a different dataset and therefore, leads to different outcome. The purpose of the present study was to evaluate several AI tools in terms of contouring accuracy and efficiency gain for five male pelvis and three head-and-neck AI tools. One AI tool has included NEMC prostate cancer patients data as part of the training set.
Materials and methods: Radiotherapist manually delineated the structure sets of 5 prostate cancer patients using Elekta Monaco workstation and all its semi-automatic tools. Delineated structures were bladder, prostate, rectum, femoral heads, seminal vesicles, penile bulb and body. CT-scans of the same patients were sent to five AI tool manufacturers and delineated structure sets were returned. Radiotherapist then edited the automatic contours until the clinically acceptable results were achieved. AI tools used were TheraPanacea, Mirada Medical, MVision OY, RaySearch and RadFormation.
Radiation oncologist manually delineated 5 head-and-neck cases in RayStation. The contoured structures were parotid glands, submandibular glands, brachial plexus, constrictor muscle and lymph node regions (IA, IB_L/R, II_L/R, III_L/R, IVA_L/R, IVB_L/R). CT-scans of the same patients were sent to three AI tool manufacturers, delineated structure sets were returned and editing was performed. AI tools used were MVision OY, RaySearch and RadFormation.
Efficiency gain was determined by comparing the time spent on manual delineation task to the time spent on editing automatically delineated structures. Accuracy was measured by comparing the automatic segmentation with manual segmentation by means of Dice coefficient.
Results: On average, it took 43.1 min to manually contour a prostate case. The range of time reduction provided by AI tool was between 1.1 and 67.4%, with the median value of 50.7%. The larger reduction was seen for the AI tool that included NEMC training dataset and for the tools with higher average Dice.
Manual contouring of the head-and-neck structures took on average 2.81 hours. Use of AI tools have reduced the contouring time by nearly 50%.
Conclusions: All tested AI tools reduced contouring time. Poorer results for some of the AI tools algorithms may be due to difference in contouring styles, training datasets and AI models. Including local data in the algorithm training set can give a better outcome for that same clinic.

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EVALUATING THE CLASSIFICATION PERFORMANCE OF 2D AND 3D BIPARAMETRIC MRI RADIOMICS FOR BREAST CANCER DIAGNOSIS: A PRELIMINARY STUDY

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Purpose: To compare the diagnostic performance of two-dimensional (2D) and three-dimensional (3D) radiomics analysis of Dynamic Contrast Enhanced (DCE), T2-weighted and biparametric Magnetic Resonance Imaging (MRI), in classifying malignant from benign breast lesions.
Material and methods: In this retrospective study a total of 82 histologically confirmed breast lesions (39 benign, 43 malignant), examined in a 3.0 T MRI scanner, were analyzed. Breast lesions were segmented with a two-step semi-automated segmentation algorithm of Fuzzy C-Means (FCM), considering a single representative lesion slice (2D), as well as the whole tumor volume (3D). Forty-five texture features were separately extracted from 2D single slice and 3D tumor volume, regarding the 2nd post contrast DCE time frame, T2-weighted MRI sequence as well as their combination (biparametric MRI scheme). The feature selection algorithm of Least Absolute Shrinkage and Selection Operator (LASSO) algorithm was employed, followed by the 5-fold cross validation classification model of Logistic Regression. The classification performance was evaluated in terms of area under the Receiver Characteristic Operator curve (AUC of ROC), while the non-parametric approach of z-score pairwise analysis was employed to investigate statistically significant classification performance differences ($p < 0.05$).
Results: In general, the highest classification performance both in 2D and 3D analysis was achieved by the biparametric MRI scheme. Specifically, in the 3D analysis the highest classification performance, AUC±SE=0.912±0.04, was achieved by the biparametric 3D scheme, followed by the DCE scheme, AUC±SE=0.899±0.04, and finally the T2-weighted scheme achieved AUC±SE=0.862±0.04. In the 2D analysis, the same trend was revealed as the highest classification performance, AUC±SE=0.865±0.04, was achieved by the biparametric 3D scheme, followed by the DCE scheme, AUC±SE=0.854±0.05, and finally the T2-weighted scheme of AUC±SE=0.797±0.05. Z-score test indicated that none of the AUC values differed statistically significantly, either between 2D and 3D analysis nor among the MRI schemes (all $p > 0.05$).
Conclusion: Regarding diagnosis of breast cancer, the 2D and 3D radiomic models exhibited high diagnostic performance across all the MRI schemes performance, without statistically significant differences. The finding of the comparable 2D and 3D diagnostic performance supports that the cost-effective 2D analysis should be considered a viable option in the radiomics research field.

EPOSTER ABSTRACTS – BIOMEDICAL ENGINEERING

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IOT PROTOTYPE (HAV DOSIMETER/SOUND LEVEL METER)

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The objective of this work, was to create both a prototype of a dosimeter for the measurement of hand-arm mechanical vibrations (HAV) and a prototype of sound level meter for noise measurement, to test them and use them together for measurements in environments (industry, healthcare, etc.) where the simultaneous presence of vibrations and noise requires continuous monitoring of the risks to the operators. We chose a microcontroller from the Arduino family (MKR 1010 WIFI) capable, on the one hand, of processing the data coming from the accelerometer (HAV) and the microphone (noise) respectively and on the other hand to communicate with an IoT platform (Blynk), with the aim of viewing on Smartphone via App, both any exceeding of tolerance levels (Title VIII Physical Agents of Law 81/2008) reported simultaneously on the phone display and via email, and the recording of the time trend in the Cloud of the HAV and noise values (for Post-processing) with the simultaneous graphic display on the telephone display of the temporal trend of the measured levels.The biological effects resulting from exposure to HAV and noise occur respectively for vibrations included in the range (0-1000 Hz) and for sound levels expressed in dBA. To meet these needs, a MEMS MPU 6050 -Card GY 521 accelerometer (passband from 0 to 1000 Hz) was chosen for the HAV measurement, while KY 039 was chosen as the microphone, where, with a pre-amplification immediately downstream microphone, the signal to noise ratio can be adjusted via a potentiometer. The Software, created in the Arduino IDE environment, loads the libraries necessary to allow the conversation between the microcontroller and the App on the Smartphone (WiFiNINA.h), the reading of digital data from the accelerometer output registers (Wire.h), the analysis spectral of the measured samples (arduinoFFT.h). To calculate the (analog) sound level coming from the microphone in dBA, the functions are called up in the main cycle.
The new prototype was tested “in the field” in the health sector, to carry out measurements pursuant to Legislative Decree 81/08 in the environments reported by INAIL as the most dangerous, ie “dentist drills” for HAVs and “analysis laboratory equipment” for noise. The results were validated by comparison with professional calibrated instrumentation.

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REVERSE ENGINEERING APPROACH FOR COLOUR PALETTE GENERATION OF ELECTRICAL IMPEDANCE TOMOGRAPHY IMAGES

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Purpose: Electrical impedance tomography (EIT) has been reported as a valid bedside method to assess lung aeration in patients under invasive mechanical ventilation. EIT indexed images are often represented by a proprietary colour palette and exported image data for custom analysis consist only of pixel values. List of colours and information on how pixel values are mapped to the palette are not always provided by manufacturers. Using arbitrary colour palettes could lead to data miss interpretation in clinical settings. The purpose of this work is to describe a colour palette reverse engineering approach to standardise image representation in custom analysis.
Materials and methods: After acquisition, EIT frames are stored in a nxn matrix and linearly interpolated before being displayed. A python code has been developed to reverse engineer the proprietary colour palette. The algorithm extracts the colour palette RGB intensity values starting from a screen capture of an exported frame. Each RGB triplet is then mapped to the pixel relative impedance value to represent the indexed image. Iteratively, n different colour palettes with the same scalar endpoints but different resolutions, are taken in input to generate n different frame representation outputs of the same linearly interpolated input matrix. To choose the optimal colour palette, the n output frames were compared to the reference one represented by the proprietary colour palette. Reconstruction accuracy was evaluated by comparing iso-value contour areas, computed in the same fashion, for both output and reference frames. Eleven contour lines, defined by a marching square algorithm, were calculated in the grey scale colour domain using arbitrary equally spaced threshold levels in the 20-240 range. Maximum percentage positive and negative error (Emax+/-) and error range (Erange%), between all the eleven contour areas in the

reference and reconstructed frames, were calculated in order to determine the optimal algorithm output.
Results: Symmetric error ranges were preferred, even if higher in magnitude, in determining the optimal colour palette. Best results (Emax+=3.9%, Emax-=4.5%, Erange%=8.4%) in estimating contour areas were achieved by oversampling the RGB array values by 31.6% in the positive range and 20% in the negative one. Image reconstruction accuracy is dependent on chosen threshold levels and resolution of the colour palette screen capture.
Conclusions: Standardising output pixel values to validated colour maps provides a consistent colour image representation for clinical analysis. Further work is required to optimise the colour thresholds for common EIT applications e.g. regional ventilation distribution assessment.

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AN INVESTIGATION OF MUSCLE ACTIVATION DURING SWALLOWING USING A LOW-COST SEMG DEVICE

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Purpose: The purpose of this project was to investigate the viability of an inexpensive and user-friendly portable surface electromyography (sEMG) sensor setup attached to the neck to detect different swallowing manoeuvres used in the treatment of dysphagia and swallowing musculature training.
Materials and methods: A MyoWare 2 electrode, sEMG sensor placed centrally above the trachea was used to detect biopotentials produced when the submandibular muscles were at rest, contracting and expanding. An Arduino UNO WiFi Rev2 board was used as a communication interface for the MyoWare sensor. Biopotential readings were graphed and stored on a wirelessly connected laptop. Swallowing experiments were conducted on a healthy volunteer to investigate differences between the Effortful Swallow manoeuvre and the Mendelsohn manoeuvre biofeedback exercises. 20 ml volume water boluses were used for both manoeuvres. A two-sample t-test at a 95% confidence interval was conducted on the results.
Results: A statistically significant difference (p-value = 0.02) between the Mendelsohn and Effortful Swallow manoeuvres was found. The Mendelsohn manoeuvre produced a stronger signal response than the Effortful Swallow manoeuvre. Significant to Mendelsohn manoeuvre was a characteristic initial spike followed by a plateau of the biopotential before the actual swallow, as would be expected when the volume was held in the mouth and throat muscles contracted before swallowing the bolus.
Conclusions: An inexpensive and portable sEMG sensor was successfully used to detect and graph differences in biopotential which could distinguish between different swallowing techniques. With further refinement, this sensor setup could provide an accessible, user-friendly training aid for patients recovering from dysphagia.
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VERIFICATION OF SYRIS SIMULATION FRAMEWORK FOR A TALBOT-LAU INTERFEROMETRIC PHASE CONTRAST IMAGING SYSTEM WITH A MICRO-FOCUS X-RAY SOURCE

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Purpose: To verify the simulation of X-ray phase contrast images (PCI) based on the Talbot-Lau interferometric technique using the SYRIS framework.
Material and methods: The Talbot-Lau interferometer (TLI) is composed by three gratings: the source grating (G0), the phase grating (G1) and the analyzer grating (G2) using a micro-focus X-ray source. The simulation is performed with a modified version of SYRIS [1] code to include the effect of the gratings. The object is located before G1 and the detector is behind G2. The code allows to obtain the image of simple geometrical objects defined by their complex refractive index: $n = 1 - \delta - i\beta$. The reconstruction of the TLI images was implemented in python and is based on the phase-stepping method [2]. This method consists in the acquisition of several images while G2 is moved in the perpendicular direction of the optical axis. Talbot effect and G2 periodicity causes that the intensity in a single pixel has a sinusoidal shape. The amplitude, mean value and phase of this function is related to the differential phase and attenuation introduced by the object.
Results: Simulation for the case of PMMA cylinder with a radius of 0,5 mm was performed considering a monoenergetic X-ray beam of 15 keV, a silicon G1 grating of $\pi/2$ and a G2 grating made of gold. We use the same period (5 μm) for both gratings. From the reconstruction, the differential phase and attenuation of the PMMA cylinder were obtained. These values were then transformed into δ and β parameters and compared with the initial ones. Differences with the initial δ and β values were 10% and 1% respectively.
Conclusions: We have verified that SYRIS framework is a robust tool to simulate a Talbot-Lau interferometer using micro-focus X-ray tube for the case of a monoenergetic beam. The reconstruction algorithm developed based on the phase-stepping method can recover the phase at the level of 10%.
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CLINICAL EVALUATION OF PREVENTION OF INDOOR COVID-19 TRANSMISSION WITH COLD PLASMA TECHNOLOGY

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Purpose: The scope was to evaluate the effectiveness of cold plasma technology in Covid-19 wards related to the limitation of the viral load. Air quality studies for the presence of SARS-CoV-2 were performed, with samples collected in live conditions at the Nicosia General Hospital.

Material and methods: As a source of cold atmospheric plasma emitter, PERENIO IONIC SHIELDTM (Joule Production, SIA, Riga, Latvia) was used, which generates specific groups of metals and halogens ions. Daily samples collection from wards and corridors were performed by Air to Liquid samplers, a high-efficiency technology for the safe collection of SARS CoV-2 . Then the samples were evaluated using RT-PCR. The study was performed at the General Hospital of Nicosia (Bioethics Approval- EEBK E∏ 2021.01.183; Bioethics Date: 7/9/2021).

Results: Total 284 samples were tested for SARS-CoV-2 by RT-PCR during the 80-days trials. The positive rate was 3% (9 samples). Four SARS-CoV-2 positive samples were detected in wards where the Ionic Shield operated for less than 12 hours and five SARS-CoV-2 positive samples were detected in wards where the device was acting as a vehicle. After the first observations, the plasma emitter was installed in one meter from each patient. Subsequently and while positive patients (tested in RT-PCR for SARS-CoV-2 at low cycle threshold (Ct) values <24Ct) were entering the wards no positive sample was detected in the following days. No side effects from using the device were reported. The results are backed up from a scientific cell monitoring study for in vitro samples. In vitro studies highlighted the safe operation of the device while testing various cell lines for effectiveness and side effects.

Conclusions: The study is the first straightforward evidence of the efficient inactivation of SARS-CoV-2 contained bioaerosols in hospital environments by cold atmospheric plasma. The results showed a significant decrease in coronavirus spread in covid wards and have the potential to be used as a safe and effective means to prevent virus transmission and infections. The use of safe UV alternatives that can lower the spread rate is essential to the new reality of "living with the virus". The development and implementation of new high effective technologies to prevent the spreading of airborne viruses have a high priority.

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LIVER TUMOR SEGMENTATION USING DEEP LEARNING METHOD: RESLU-NET

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Microwave ablation (MWA) as a recently developed technique in the field of tumor therapy has attracted attention. The technique has the benefit of being minimally invasive in approaching the target, enabling multiple tumor treatments, and fast ablation time by using single or multiple microwave antenna in the tumor location. The therapy destroys the tumor cells by generating heat in the tissue. Using Computed Tomography (CT) the tumor is localized and the therapy is finalized. However, the low contrast between tumor and healthy tissue in CT images of MVA liver therapy makes the tumor localization and segmentation a very challenging task. Therefore, there is an immediate need to precisely segment the tumor and ablated area in order to be certain of enough ablation and preventing tumor recurrence and reduce the exposure of the patient to ionizing radiation [1].

A customized and automatic image segmentation would be helpful to separate the healthy, the tumor, and the ablated tissue in CT images during liver MVA therapy. Artificial intelligence as a new technique in medical image segmentation can be employed to assist the physicians in their task which is usually knowledge-based for making the important decisions during the therapy. The immediate goal is to improve a segmentation method based on one of the traditional segmentation methods such as VGG, Res-Net, U-Net, Seg-Net. Among them, U-Net has outperformed the prior best method in biomedical imaging. However, there is a need for performance improvement of the segmentation model in the interventional CT image modality system. In this regard, we propose a new deep learning method called 'ResLU-Net' based on the U-Net model. With the help of the ResLU-Net model, the segmentation process will be optimized by reducing the error in the conventional U-Net model [2,3,4].

The data collection has been performed using a clinical CT scanner from the University hospital Magdeburg, Germany. The dataset contains CT images of 25 patients which vary in age, gender, tumor size, shape, and location. The method segments the tumor, healthy and ablated tissue on CT images. The pre-processing steps contain data sampling and augmentation – the latter one to overcome the problem of a small dataset. The results can be compared with the conventional U-Net model. The model will be also tested on a new dataset generated by adding noise on the original dataset, simulating a reduced image quality compared to the original CT images to highlight the potential for dose reduction.

EPOSTER ABSTRACTS – DIR

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INFLUENCE OF OPTIMIZATION ON PSYCHOPHYSICAL METRICS OF CT BRAIN EXAMINATIONS

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Computed Tomography (CT) technology has been growing extensively with capability to provide acquisition at lower exposure but with better image quality. Several techniques have been proposed and some are commercialized for the betterment of patient care. However, several drawbacks were observed during the process including the blotchy images due to utilization of iterative reconstruction algorithm. Hence, this study aimed to evaluate the CT brain image quality performance by measuring the noise power spectrum (NPS) as metrics indicator and to compare the different optimized protocols while incorporate the psychophysical metrics. A head-based water phantom was scanned on our in-house 128-slice CT scanner and performed with various protocols based on the established recommendation for optimizing dose to CT brain examinations. For each protocol (P1-P8), the tube current was maintained at 120 kVp and changes the tube current, IR algorithm and automated mA protocols. Five ROI circle with size of 100 mm2 was placed on the images to average the mean, SD, SNR and NPS. The contrast dependent spatial resolution and the Figure of Merit (FOM) were measured and analyzed. Based on the observation, we indicate that NPS peak for P2, P3 and P4 were shift to the right on 0.063 mm-1 while P1 at 0.043 mm-1. Furthermore, the P2, P3 and P4 shows a higher spatial frequency, but P1 has a better NPS. This study found that the choices of IR setting and automated mA setting combination as parameter changes does not surpass the score of the

standard parameters produced. Hence, high setting for quality mA provides best results in term of SNR and NPS.

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PATIENT DOSE, IMAGE QUALITY AND BODY HABITUS DESCRIPTOR SURROGATES FOR ABDOMO-PELVIC CT: AN UPDATED COMPREHENSIVE SYSTEMATIC LITERATURE REVIEW

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Purpose: Effective optimisation in abdomino-pelvic CT hinges on the use of relevant and accurate estimations of patient risk (surrogates being patient dose quantities), diagnostic accuracy (surrogates being image quality descriptors) and body habitus descriptors in order to tailor protocol optimisation to body size and morphology (and ideally clinical indication). The objective of the literature review was to provide an update of the definitions and different methods for measuring these three categories of descriptors, together with their respective strengths and limitations.
Materials and methods: This literature review was initiated using the following electronic research databases: Google Scholar, Scopus, PubMed/MEDLINE, IEEE Xplore, and Web of Science until 10 October 2021. Articles were analysed under the following themes: (1) title, author/s, year of publication, country of origin of first author (2) research design, data collection tool, CT device manufacturer and model (3) sampling method, number of participants (4) results (5) strengths and limitations. Relevant references cited in the reviewed articles were also included. The key words used were: computed tomography, CT, patient risk, patient dose, diagnostic accuracy, sensitivity and specificity, image quality, body habitus.
Results: Patient risk surrogate quantities defined and the methods of measurement of which are described are the CTDIvol, DLP, SSDE; the diagnostic accuracy surrogates are the Global Noise Level, Tian and Samei Noise; the body habitus descriptors are WED, patient cross-sectional area, circumference and diameters and superficial fat area.
Conclusions: This review provides an updated comprehensive summary of surrogate descriptors for patient risk, diagnostic accuracy and body habitus suitable for optimisation studies.

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MATERIAL IN SUPPORT OF THE IAEA PUBLICATION ON REMOTE AND AUTOMATED QUALITY CONTROL FOR RADIOGRAPHY AND MAMMOGRAPHY

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Purpose: The IAEA supports the application of best practices in all specialties of medical physics, through providing guidance, dosimetry codes of practice and offering related training. Accordingly, the Human Health Series No. 39 "Implementation of a Remote and Automated Quality Control Programme for Radiography and Mammography Equipment" was published in October 2021 to facilitate routine testing of radiography and mammography equipment, and collection and analysis of data from different centres.
Material and methods: To enable and enhance implementation, accompanying material was developed and training material was produced to standardize dissemination.
Results: A dedicated page was created on the IAEA Human Health Campus (HHC) to host the material (Human Health Campus - Remote/Automated quality control in Radiology (iaea.org)). This includes: spreadsheets to ease the documentation of results; real size blueprints of the proposed phantoms (radiography, mammography) to help in local construction by the users; dedicated software to automatically analyse phantom images and provide advanced and sophisticated measures of image quality and a user manual of the software. Additionally, slides and frequently asked questions (FAQs) have been prepared to support training courses.
Conclusions: In alignment with a structured educational approach, the IAEA has provided training material and tools to accompany the IAEA publication HHS No. 39 and encourage its dissemination among Member States. The training material and in particular the FAQs, will be updated to best reflect the inputs received from the users. Feedback from users is encouraged at NAHU-Dosimetry. Contact-Point@iaea.org.

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RETROSPECTIVE STUDY OF DOSE REFERENCE LEVELS IN HEAD CT STUDIES IN A HEALTHCARE AREA WITHOUT EXPERIENCE IN PROCEDURE OPTIMISATION

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Purpose: One of the most important roles within the profession of medical physics is the estimation of delivered doses and the establishment of DRL (Dose Reference Levels) in order to optimise radiological procedures. One of the devices where most radiation is delivered is Computed Tomography Scan (CT-Scan), so optimising the procedures of this modality will be transcendental for good practice. Law 601/2019 of 18th October on justification and optimisation of ionising radiation use (Spanish legislation transcribing chapter VII of Euratom Directive 59/2013), places special emphasis on the control of dose levels in this kind of procedures. The aim of this study is to assess the dose reference levels for head CT procedures on different CT rooms for several healthcare facilities that did not have medical physics specialists until now.
Materials and methods: The study was performed with the CTDI (Computed Tomography Dose Index) values recorded by the DOSE dose management system from Qaelum. The devices for which recorded data was analysed were 4 General Electric CT-Scans, LightSpeed 64-slice model and 1 BrightSpeed 16-slice model, and 1 Canon Aquilion One 320-slice CT. The CTDI recorded from a total of 2930 studies was analysed, obtaining the median of head studies from each CT, as well as the 75th percentile of the different medians, thus obtaining the dose reference level in this procedure.
Results: The median CTDI values obtained from each of GE LightSpeed procedures are 117.62, 158.94, 97.16 and 80.03 mGy. The median obtained from the GE BrightSpeed CT is 117.71 mGy. The median obtained from the Canon Aquilion One CT is 54.7 mGy. The 75th percentile of all these values is 117.68 mGy.
Conclusions: From the obtained results, a large dispersion of CTDI values for the head procedures analysed was observed between the different CT rooms reviewed, even between rooms with the same model of CT equipment. In almost all the wards, the recommended dose reference levels CTDI of 60 mGy were exceeded, in some of them by as much as 165%. All these results prove the need of

vigilance and monitoring by the medical physicist, the need to optimise procedures and the importance of our work in this field.

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COMPARISON OF TWO AUTOMATIC METHODS FOR SVD LESION SEGMENTATION IN MR IMAGING: A PRELIMINARY STUDY

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Purpose: Small Vessel Disease (SVD) is a condition that causes brain bleeding and contributes to cerebral infarction and vascular dementia. Although SVD brain lesions appear quite similar to the ones due to Multiple Sclerosis (MS) in MRI images (hyperintense areas in FLAIR images), in the literature they have not received as much attention and no public resources are available for their classification. As manual segmentation it is very demanding, in this study we investigate the possibility to exploit two automatic segmentation methods developed for MS lesions and fully available from the internet for SVD lesions.

Material and methods: For this preliminary study six patients with SVD were selected from a larger dataset. The clinical MRI acquisitions protocol includes volumetric 1mm^3 isotropic T1-weighted and FLAIR images. For each patient manual segmentation of the SVD lesions was operated by five neuroradiologists on the FLAIR image. From their segmentations a ground truth segmentation was created by means of STAPLE algorithm for each patient. The two available automatic software, originally presented in the literature for MS lesions, were applied to SVD lesion detection. The first method is SLS (Salem Lesion Segmentation), a tool of the SPM Matlab suite. The second software is a convolutional neural network (CNN) already trained for MS lesions. The automatic segmentations were compared to the ground truth with the estimation of the Dice index and the true positive rate (TPR) to assess their accuracy.

Results: The Dice index and TPR over the six patients have resulted quite consistent with the ones reported in the literature: SLS has a mean Dice index of 0.78 and a mean TPR of 0.72; the CNN has a mean Dice index of 0.73 and a mean TPR of 0.78.

Conclusions: The results of this preliminary work, although in agreement with the literature, demonstrate that the automatic segmentation methods might not be satisfactory in comparison with manual segmentation. The main critical issue is that the two methods are designed for a different classification task. We are currently working on a CNN trained on SVD segmented images from the larger dataset as in our opinion this could greatly improve the performances of the network.

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CARDIAC ANGIOGRAPHIC PROTOCOLS: A FIGURE OF MERIT APPROACH

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Purpose: The purpose of this work is to compare cardiac angiographic protocols between different systems evaluating a figure of merit (FOM) that correlates image quality and entrance dose (ED). The high contrast resolution of the two systems was also compared.

Materials and methods: Measurements were performed on different angiographic systems (System A, B and C). Low dose cardiac protocols, the most used in the clinical practice, and "normal" or "medium" dose protocols were considered. Exposure parameters and added filtrations were automatically selected by AEC. Leeds TOR18FG phantom placed in the middle of 20 cm of PMMA, simulating a patient, was imaged and simultaneously ED was measured. To evaluate image quality we calculated SNR on different fluoroscopic and radiographic images.

A FOM was calculated as SNR^2/ED. For System B was also evalued the difference in terms of FOM between different detail levels (normal or low). The set of images obtained were analysed using Imagej.

The high contrast resolution was evaluated with the automated software AUTOPIA v 3.7.1.

Results: In relation to low dose fluoroscopy System B has a higher figure of merit compared to System A and C (762 1/nGy vs 191 1/nGy and 238 1/nGy respectively for the first detail of the phantom). The same consideration can be made for cinenagiography scans (810 1/nGy for System B and 154.2 for System A).

As it can be seen System A has a better performance in terms of high contrast resolution than System B and C. MTF50% for low dose fluoroscopy exposure was respectively 2.04, 1.25 and 1.24).

Conclusions: Preliminary results show differences in signal to noise ratio values and subsequently in FOM values between system A, C and B. This is probably due to a different reconstruction algorithm: in System B noise is reduced thus SNR increase at the expense of high contrast resolution.

Regarding to System B, low detail level yelds to a higher figure of merit than normal detail level, both for low dose and normal dose protocols.

Any exposure parameters determined by optimal FOM need to be further investigated. Next step is to extend these procedure to analyze other angiographic systems performance.

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MANAGEMENT OF PATIENTS WITH IMPLANTABLE MEDICAL DEVICES UNDERGOING MRI EXAMINATIONS: AN INTERDISCIPLINARY PROCEDURE

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Purpose: In recent years, the number of Cardiac Implantable Electronic Devices (CIED) is steadily increasing, representing a potential critical aspect in performing MRI-scans. Therefore, the introduction of MR-conditional devices has extended the benefits to those patients as well, under controlled conditions according to the manufacturer's instructions.

This study aims to describe the interdisciplinary safety procedures adopted for these MRI-examinations, paying particular attention to the application of the technical recommendations provided.

Material and methods: Since 2017, an interdisciplinary protocol have been adopted to identifying a pathway for patients with CIED. This is codified and shared with the healthcare professionals

involved in the MRI examination phases, including Radiologist, Electrophysiologist and Medical Physics Expert (MPE).
Different effects are generated on CIEDs and relative catheters during MR-scans: mechanical ones due to the static magnetic field, interferences caused by the gradient field and thermal effects determined by the radiofrequency. The last one is the most critical as it can cause necrosis of the tissue surrounding the electrodes and interfere with the stimulation threshold; it is expressed in terms of Specific Absorption Rate (SAR) [W/kg] and depends on multiple parameters, as patient weight and type of sequence.
To date, approximately 160 head, body and cardio examinations have been performed on four 1.5T scanner, involving patients with MR conditional devices. The tracking software NEXO[DOSE]® (Bracco Injeneering, Lausanne) was used to retrospectively assess whether the technical parameters prescribed by the MPE were actually respected.
Results: All patients were successfully scanned without significant changes in the programmed parameters.
Despite this, on average 26% of examinations were performed without adhering to recommendations provided. However, the incidence of exceeding the normal operating mode for CIED patients is lower respect to the totality of MRI performed in the same period. In fact, the examinations exceed the SAR thresholds resulted equal to 41%, ranging from 28% to 62%, from 49% to 78% and from 8% to 10% for cardiac, body and head scans respectively.
Furthermore, after specific training course delivered to radiology technicians, the requirements were more closely adhered (head=6%, cardiac=13%, body=25%).
Conclusions: It is possible to manage this type of patient with a dedicated protocol, identifying the risk arising from these technologies.
Further improvements will include training courses and optimization of the most critical sequences, to achieve both SAR compliance and adequate image quality.
A tracking tool is essential to retrospectively analyze and verify how the transmitted indications are actually applied.

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CHALLENGES EVALUATING CT NUMBERS IN "OTHER MATERIALS"

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Purpose: Testing of CT number accuracy is a key part of CT Quality assurance (QA). A common issue encountered by physicists is when a value drifts more than 10HU from baseline for "other materials" as specified in IPEM Report 91. Manufacturer QC tests routinely check air and water and when they are within specification there is little that can be done to correct for the other material which has drifted outside baseline. This study investigates the differences in testing criteria of CT number values across all the international guidance. IAEA only require testing of CT numbers for water. The ACR method requires testing of water at all energies but only other materials at 120kV. The ACR give a defined range for each material while IPEM guidance states +/- 10HU from baseline.
Materials and methods: International guidance on CT QA assessments were reviewed from IPEM 91, AAPM TG233 and IAEA Human Health Series No.19 as well as the Catphan and ACR CT manuals and specifications. QA records over the lifetime of five CT scanners from two vendors in one hospital group were reviewed.
Results: Analysis of the QA results from the lifetime of five CT scanners found several instances where the CT numbers of Teflon and Delrin deviated more than 10HU from baseline. The vendors confirmed that the CT numbers for water and air were within specification after an air calibration. Physics testing on the next occasion often yielded results outside baseline again.
Conclusion: This study shows significant differences for assessing the accuracy of CT numbers in the published guidelines. While the Catphan manual gives ranges for the CT numbers of different materials they state that numbers outside that range are not unusual. If the ACR criteria was applied, the measurements for Teflon on all scanners reviewed for this study would have been in tolerance as there is a wide range set and not a deviation from baseline as per IPEM guidance. Furthermore as some scanners did not permit scanning at 120kV, Teflon and other materials would not have been tested if using the ACR method. If the IAEA method was used no issues would have been identified on QA as only testing on air and water are required. The results of this study shows the need to establish a consensus for assessing the performance of the diagnostic CT scanner in terms of CT numbers.

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A COMPARATIVE STUDY OF INTERNATIONALLY USED CONSTANCY TESTING PROTOCOLS FOR DIAGNOSTIC AND INTERVENTIONAL RADIOLOGY X-RAY SYSTEMS

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Purpose: Given the variation in protocols and tolerances prescribed by different international standards and medical physics organisations, this work sought to carry out a comparative study to highlight similarities, differences, and relative strengths and weaknesses with a view to help Medical Physicists develop constancy testing protocols suitable for their local context.
Material and methods: The methodology that was used in this study was a comparative qualitative documentary thematic analysis of constancy testing protocols published by the International Electrotechnical Commission, European Commission, International Atomic Energy Agency, Institute of Physics and Engineering in Medicine, American Association of Physicists in Medicine and American College of Radiology. The thematic categories and labels that were analysed were: Document Metadata (Document Number, Recency, Price of Document), Equipment used in the constancy testing (Equipment required, Expense of Equipment, Ease of Availability), Measurement Protocol for constancy testing (Professional Performing the Test, Level of Complexity), Test Frequency and Tolerance Limits. The scope was limited to the following modalities: digital radiography, digital mammography, fluoroscopy and computed tomography.
Results: The thematic analysis showed that there isn't one specific organization that publishes suitable constancy testing protocols for all the selected imaging modalities.
Conclusions: Given the variation between documentation, it was concluded that Medical Physicists should peruse a multitude of documents to garner good practice elements from more than one organization when setting up own protocols. Generic recommendations for specific imaging modalities are put forward.

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A METHODOLOGY FOR ANALYZING THE NOISE TEXTURE AND UNIFORMITY IN MAGNETIC RESONANCE IMAGING (MRI) BASED ON NOISE POWER SPECTRUM (NPS) MEASUREMENTS USING ACR MRI PHANTOM

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Purpose: Due to increasing involvement of MRI modality in advanced diagnostic and radiotherapy workflows, quality assurance of MRI facility has become a high concern. The purpose of this work is to propose a new methodology to characterize more accurately the noise and uniformity of MRI images based on noise power spectrum (NPS) measurements.
Material and methods: The large American College of Radiology (ACR) MRI phantom was used as an object test for the measurements. Acquisitions were carried out on MRI facility (Optima MR450w 1.5T GE Healthcare), with a head coil, using weighted T1 and weighted T2 acquisitions according to ACR accreditation program. 2D-NPS measurements were performed in both non-signal background and signal homogeneous image. Variance was calculated from integral of the 1D-radial NPS, then structured and white noises were separated. White noise values were compared to noise estimated by other methods reported in literature. Relative Structured Noise Index (RSNI) was used to assess the image uniformity, which represents the ratio of the structured noise to total noise, measured from signal homogeneous image. The results were compared to the uniformity calculated from NEMA method. Impacts of acquisition parameters (Matrix, Field-of-view, Band Width and filters) on the NPS curves are studied. To show the reproducibility and reliability of this method, the measurements were weekly performed over 15 months, then statistical analysis were performed by providing chart controls over time. All analyses were automatically processed with an in-house program (MATLAB software).
Results: NPS curves calculated from signal homogeneous image showed white and non-correlated noise over spatial frequencies. However, NPS calculated from non-signal background, showed decrease of noise magnitude by a factor of 0.66±0.01 (agreement to theoretical calculation) and the noise amplitude decreased with spatial frequencies, showing more correlated noise. Noise measured using NPS method showed a good agreement compared to NEMA calculation methods. Considerable changes were observed in both shape and amplitude of NPS with acquisition parameters or sequence type. RSNI was more sensitive to any uniformity drift and showed a stronger correlation to human observer than NEMA method used for uniformity assessment.
Conclusion: NPS measurements estimate the noise directly from signal homogeneous images without being affected by any ghosting or drift artefacts. RSNI could be a powerful metric to assess image uniformity in MRI. Our methodology could be useful for evaluating clinical sequences and can easily be implemented in routine quality control.

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DEVELOPMENT AND EVALUATION OF A POST-PROCESSING PIPELINE TO ENHANCE 0.35 T PELVIC MR IMAGE QUALITY

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Purpose: MR-LINAC systems offer high soft-tissue contrast volumes thanks to the on-board MR-scanner. However, low frequency intensity inhomogeneity artifacts can occur, resulting in signal losses that may affect the image quality (IQ). Various correction strategies have been proposed to reduce such artifacts on high-field MRIs and very limited cases are focused on 0.35T ones. This study aims to outline and assess an image processing pipeline able to enhance the IQ, offering a better visualization of targets and organs-at-risk, and to obtain reliable intensity distributions for the subsequent digital processing, such as auto-segmentation.
Material and methods: The study was carried out on clinical 0.35T MRIs (ORIG) from 20 prostate cancer patients treated with MR-LINAC. The N4-bias-field-correction (N4ITK), alone or in conjunction with an Adaptive Histogram Equalization filter (N4ITK_AHE), was applied to the images. Two experienced radiation oncologists (O1,O2) blindly scored overall IQ and prostate's boundaries visibility of the ORIG, N4ITK and N4ITK_AHE images, using a visual grading (VG). The Friedman Test was used to determine the statistical significance difference in applying the two correction pipelines. The IQ improvement was also quantitatively evaluated by computing the ratio between the pixels' intensities standard deviation (σ_ratio) post- and pre-filters application, and the ratio between the Shannon Entropy (SE_ratio) post- and pre-filters application, inside the body.
Results: Concerning the VG analysis, the N4ITK application improved the IQ in 15% and 20% of cases, while the N4ITK_AHE resulted in better IQ in 25% and 5%, for O1 and O2 respectively. Moreover, the prostate boundaries' visualization increased in 15% and 24% of observations after N4ITK application and in 35% and 18% after N4ITK_AHE implementation, for O1 and O2 respectively. The Friedman test showed that there was no statistical difference across the modalities for either O1 ($p=0.236$) and O2 ($p=0.325$) IQ scores. For the prostate delineation, a significant improvement was observed in applying the filters ($p=0.034$) for O1. From a quantitative perspective, σ_ratio and SE_ratio were both less or equal to 1 for all patients, with a mean value equal to 0.72 and 0.93 in the N4ITK/ORIG comparison, and 0.93 and 1.01 in the N4ITK_AHE/N4ITK comparison, respectively.
Conclusions: Based on this preliminary work, the N4ITK and N4ITK_AHE application on 0.35T MRIs results in either an improvement or no change of both overall IQ and prostate visualization in clinical practice. Results are also supported by quantitative metrics, showing a decrease in signal dispersion. Ongoing multidisciplinary work will allow further evaluation.

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T2 RELAXATION TIME AS TEMPERATURE MEASUREMENT TOOL

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Purpose: The purpose of this work was to quantify the T2 relaxation time as a function of temperature in mild hyperthermia, in order to

control the T2 index as a way of measuring temperature changes during the hyperthermia process.
The T2 parameter was measured for three samples. They had electrical properties (conductivity) that resembled various tissues at 37°C. The first solution had conductivity which was resembling fat, the second grey matter, and the third cerebrospinal fluid.
Material and methods: The three solutions were placed in tubes of 10mL
each, and then in a Polytetrafluoroethylene base. Teflon has dielectric properties that remain stable with frequency and temperature.
Each tube's ending had a special recess so that the 3 fluoroptic channels could be placed inside the solutions in order to perform temperature measurements.
This tap was a three-way stop tap with a lure lock which provided stability of fluoroptic thermometers during the experimental process.
The base with the three solutions was placed on the calibration plate and inside the MRI head coil.
The tube used as a waveguide was made of aluminum and stainless steel with a diameter of 18cm.
As a Hyperthermia system, a Microwave Diathermy device named Fisiowave was used. The diathermy antenna was placed in the recess of the waveguide and sent microwave pulses of 2.45GHz.
The diathermy machine was operating in continuous wave mode, sending a total of 100–200watt, in order to increase the temperature of solutions until to achieve microwave hyperthermia temperatures.
Using HASTE Sequence, images were obtained after each process of heating. The temperature of the solutions was monitored in real-time utilizing TrueTemp software.
After the heating process, the conductivity of the solutions was measured using HI-2030 Edge from 45–20°C with natural cooling procedures.
Results: Linear regression for the resembling solutions' relationship between T2-T:
Fat: $T2(T)=(19.35\pm0.89)\cdot T+(1584\pm35)$
GM: $T2(T)=(37.78\pm1.50)\cdot T+(1292\pm48)$
CsF: $T2(T)=(38.35\pm0.90)\cdot T+(1369\pm32)$
Conclusions: From the T2 versus Temperature plots, r (index)=1, throughout every analysis.
This suggests that the relaxation time T2 can be a great indicator that can sensitively measure temperature changes during the hyperthermia process.
For solution which resembled Fat, the T2-T plot gives r=1, $P<0.001$ for six measurements (n=6).
For the solution resembling Grey Matter, r=1, with $P<0.001$ for n=6, as well.
For the solution resembling CsF, r=1 with $P<0.001$ and n=6.

EPOSTER ABSTRACTS – E&T

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TWO IAEA E-LEARNING COURSES IN MEDICAL PHYSICS: MONITORING PROGRESSION AND PROFESSIONAL PROFILE

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Purpose: The IAEA supports its Member States through building capacity in all specialties of medical physics, by providing guidance, promoting the recognition of medical physicists as health professionals, and disseminating best practices and guidelines through specialized training, including e-learning. In 2021, the IAEA released two self-paced e-learning courses in diagnostic radiology medical physics. Such courses are designed to provide access to continuous professional development (CPD) activities to an audience of clinically qualified medical physicists (CQMPs). The e-learning courses are organized in sequential modules that are accessible to the user subject to the successful completion of self-assessment tests at the end of each module. At the end of the e-learning course, the users may download a proof of completion, detailing the content and duration of the course, which can be used for obtaining CPD points in their local system. The e-learning courses are freely accessible but require registration.
Material and methods: The e-learning courses are hosted on the IAEA CLP4NET learning management system, based on Moodle. Regular quantitative monitoring of progress is conducted and linked to anonymized registration details. Information on the course enrolment and completion rates, for instance, are extracted from the analysis of the intra-module self-assessments. The trends delineated from the two diagnostic radiology courses (one on digital radiology and one on mammography) have been extracted, described and compared. Additionally, qualitative feedback is obtained from a course evaluation form.
Results: The monitoring of the e-learning modules has demonstrated an interest in access to CPD material in the area of diagnostic radiology medical physics. The e-learning course audience is consistently representative of the target professional group and the progress through the courses is in line with the course design strategy.
Conclusions: The identification of specific indicators and their cyclical monitoring over time, provides quality assurance and useful information on target audience outreach and course design structure.

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NETWORKING MEDICAL PHYSICS WITHIN EUROPE AND IN THE WORLD: THE CASE OF THE ADVANCED MASTER IN TRIESTE

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Purpose: The Master of Advanced Studies in Medical Physics (MMP) run jointly by the University of Trieste and the International Center for Theoretical Physics (ICTP) is an international 2-year "master after the master" that has graduated more than 100 medical physicists from all continents. Ten of them are from Europe. This is a survey of the effect of this program on European medical physics, in terms of improving networking inside each country, within Europe, and outside.
Methods: The online survey of MMP graduates from European countries was performed concerning their professional activities and roles at national and international levels.
To evaluate the role of the MMP program on improving networking and status of medical physicists, the online survey included questions regarding professional activities prior to joining the MMP program and after graduation. There were 7 MMP graduates included in this study from the following European countries: Belarus, Estonia, Georgia, Latvia, and Montenegro.
Results: The online survey demonstrated that the Master of Advanced Studies in Medical Physics has improved the network of European

medical physicists by establishing strong international connections not only between MMP students from different European countries but also between MMP students and Italian medical physicists (supervisors, professors, and other Italian medical physicists). 7 Medical physicists responded that after graduation they remain in strong connection with their Italian supervisors. As well, all 7 respondents have established new international collaborations with international organizations (EFOMP, EURADOS, ESTRO, and IAEA). 4 Medical physicists have become members of their national associations or societies of medical physicists, and 3 have become members of EFOMP. 5 Medical physicists after graduation have been involved in teaching or supervising activities and one has been involved in research activities.

Conclusions: From the survey, it was concluded that the European network of medical physicists is continuously growing and with the help of the MMP program, the number of medical physicists from developing countries within international organizations is currently increasing.

The graduates of the MMP program have established strong international collaborations and currently are involved in numerous national and international activities. The graduates have a positive influence on raising the general level of the medical physics field.

Therefore, it was concluded that the MMP program has improved the networking and status of medical physicists and the viability of the medical physics profession inside European countries.

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TRAINING AND TUTORING FOR THE EXPERTS OF NUCLEAR REGULATORY AUTHORITIES OF COUNTRIES OUTSIDE THE EU

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The safe utilization of nuclear energy requires competent, independent, and adequately financed National Nuclear Regulatory Authorities (NRAs) and Technical Support Organizations (TSOs). Because of the high demands on technical competence, the continuous availability of new information (development of new reactor types, new safety mechanisms or new assessment methodologies, new medical radiation techniques), the recruitment of new staff, there is always a need for general, in-depth and specific training for the experts of NRAs and TSOs to build and maintain their necessary knowledge and skills. The European Union (EU) supports the achievement of the above in countries outside the EU through the Instrument for Nuclear Safety Cooperation (INSC) and has initiated several actions to provide training for countries in need of technical assistance.

The Training and Tutoring initiative to support competence building worldwide is part of the efforts of INSC towards making the EU a global reference in matters of nuclear safety and radiation protection, emergency preparedness and regulatory framework, not only for nuclear energy but also for medical application related to nuclear medicine, radiotherapy and diagnostic imaging.

Phase 5 of the INSC project of the European Commission was launched in January 2022 and implemented by a Consortium led by EK (Hungary), having members of NucAdvisor (France), N.IN.E. S.r.l. (Italy), VUJE, a. s. (Slovakia), Uni-Energy Ltd. (Hungary) and the ENEN (Belgium). Throughout the nearly three years of the project, several courses – both in the form of trainings and several weeks tutoring – and assistance will be provided for the experts of NRA(s) and TSO(s) of non-European Union countries to strengthen their capabilities with regard to their tasks and responsibilities related to radiation protection and nuclear safety. Developing such expertise is more than a matter of education, as it involves not only the transfer of technical knowledge, experience, and best practices, but also helps promote nuclear safety and radiation protection culture. In addition to details of the programme, initial results and lessons learnt will be presented.

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CHANGING MIND-SETS - IMPLEMENTING A CHANGE IN CULTURE AND PRACTICE THROUGH DEMONSTRATION, EDUCATION, AND SCIENTIFIC REVIEW

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Purpose: One of a parent's main concerns when bringing their child for an X-ray is the exposure to ionising radiation. They are reassured by the use of protocols and equipment that is set-up specifically for paediatrics. They also like to see the use of contact shielding to protect radiosensitive organs, such as the gonads. However, recent publications have recommended the cessation of most forms of patient shielding, as research, along with advances in imaging technology, have shown that it provides little benefit and can potentially cause issues with image quality.

This change in practice not only needs to be communicated to the patient and their parent/guardian, it also needs to be accepted by the radiology community. This work discusses the challenges in the implementation of this practice change in a paediatric hospital.

Material and methods: Prior to the changes, gonad shields were routinely used during pelvis or hip exams (primary shielding). Secondary shielding, such as half lead aprons were also used to protect the gonad area during chest or extremity X-rays.

The change in practice was introduced in a number of ways.

1. Stakeholder engagement – disseminated published recommendations for review by key members of senior radiology staff.
2. Feedback – took on board concerns raised regarding the exposure of radiosenstive organs either in the primary beam or from scatter radiation.
3. Undertook surface dose measurements to estimate the dose to the patient. Measurements were taken at locations where contact shielding was traditionally placed, for either primary or secondary purposes.
4. Communication of published recommendations and in-house results via a series of staff presentations.
5. Communication of change to parents and referrers thought posters and prepared Q&As.

Results: As it is well publicised that contact shielding of the gonads can lead to repeat imaging due to incorrect placement, this practice change was welcome by most staff. However there was more reluctance when it came to the removal of secondary shielding. Through experiments demonstrating the negligible amount of scatter, as well as group discussions on individual concerns, the change in practice was successfully introduced. This lead to a consistent approach in patient protection throughout the organisation and gave confidence to the radiographers when they explained the change and its benefits to concerned parents.

Conclusions: Education through demonstration and scientific review is an important tool to bring about change in any environment, especially one where patient safety is key to all stakeholders.

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ILFISICOMEDICORISPONDE (THEMEDICALPHYSICISTANSWERS): THE IMPORTANCE OF EMPATHY IN SCIENTIFIC COMMUNICATION

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Ilfisicomedicorisponde (themedicalphysicistanswers) is a free service aimed at the public by the Italian Association of Medical Physics (AIFM) since 2013. It can be accessed on the AIFM website, via forum or email.

The intent is to disseminate information on topics of medical physics interest to the public by contrasting information without scientific basis, running specifically on the web and which can lead to a non-objective risk perception.

To date, access to 'ilfisicomedicorisponde' is around 30,000 visits per month. The topics of greatest interest concern are diagnostic exposures, in particular in pregnancy and pediatrics.

The 'ilfisicomedicorisponde' experience has highlighted the importance of empathic communication in scientific issues with the people of the public. Communicating scientific data to the public presents indeed many difficulties to be overcome, such as: lack of familiarity of the public with the subject, acquisition of information from non-scientific sources and not subject to peer review (websites, mass media, friends, ..), perception of some beliefs as truths easily transmitted among people.

Informing effectively is not transmitting information to the public considered as an entity. Informing effectively needs to consider the uniqueness of the person and of her/his life. Active and empathic listening is a powerful tool to understand the reasons for a subjective perception of risk, often misrepresented and therefore a reason for anxieties and fears that can lead to behaviors, sometimes too extreme (eg: abortion). After all, medicine is increasingly precision medicine, in an attempt to personalize prevention, diagnosis and treatment as much as possible on the basis of the individual patient.

People main fears concern negative effects of medical exposure to radiation, highlighting skepticism in justification and lack of awareness of the benefit that can be drawn from a diagnostic test.

The main request is the quantification of individual risk, which is impossible to provide. So it is fundamental to deeply understand the fears of the person, to talk about them with empathy so to convey the concepts of probability and benefit/risk ratio.

To achieve a more effective communication, answer provided by 'ilphysicsmedicorisponde' experts are often customized, both in terms of content and modality.

In order to improve the communication aspects, it is necessary to expand the collaboration of this project not only to medical figures, as is currently, but also to citizens' and patients' associations and communication experts.

EPOSTER ABSTRACTS – INFORMATICS

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GPU-ACCELERATION OF SPARSE LINEAR ALGEBRA IN RADIOTHERAPY TREATMENT PLAN OPTIMIZATION WITHIN THE OPEN-SOURCE RADIOTHERAPY PLANNING TOOLKIT MATRAD

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Purpose: The transfer of algorithms to graphics cards has become an integral method to accelerate numerical computations, not only in radiotherapy treatment planning. Apart from the multiple Monte Carlo GPU dose calculation implementations, publicly available GPU-accelerated algorithms for radiotherapy treatment planning are scarce. For the open source treatment planning toolkit matRad written in MATLAB, we investigate the potential of GPU acceleration during plan optimization, particular for sparse linear algebra operations involving the sparse dose influence matrix.

Material and methods: Two GPU acceleration concepts were investigated: (1) using the high-level GPU-operations implemented in MATLAB's Parallel Computing Toolbox, and (2) using a C++ MATLAB MEX interface to CUDA's cuSPARSE Library. In the first approach, the dose influence matrix is copied to the GPU using Matlab's "gpuArray" datatype, automatically handling the data transfer and overloading the matrix multiplication operators, while being inherently limited to double precision. The second approach uses a custom Matlab datatype to handle single precision sparse matrices, overloading matrix multiplication operators to forward the matrix to cuSPARSE. The implementations are used to compute the sparse matrix vector products for objective function and gradient computation during numerical optimization of multiple treatment plans for photons and protons with varying complexity. The used optimization package IPOPT implements only CPU computations, resulting in data transfer overhead of objective function value and fluence gradient in each iteration.

Results: Runtime comparisons of the bare sparse matrix vector computations on an NVIDIA GeForce 1080 compared to CPU computations on an Intel Core i5-8600K indicate large acceleration in performance with a factor of 2.3-4.2 for implementation (1) and a factor of 9.4-17.3 for implementation (2), primarily depending on the size and non-zero entries of the sparse matrix. Due to the additional overhead, the benefit is less pronounced measuring a full treatment plan optimization, where runtime improvements range from 1.8x times acceleration for implementation (1) to 3.2x acceleration for implementation (2).

Conclusion: The implementation shows how open-source radiotherapy tools like matRad can greatly benefit from just simple GPU-acceleration. Further acceleration may be achieved by interfacing a matrix-free optimizer running on the GPU itself to avoid unnecessary data transfer during each optimization iteration, and by using tensor processing units in latest-generation GPUs. Beyond radiotherapy, the study shows that MATLAB itself would greatly benefit from introduction of single precision sparse matrix computations on the GPU, given the current limitation to double precision sparse matrices and potential broad range of applications.

EPOSTER ABSTRACTS – NM

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APPLICATION OF A NOVEL TIMEPIX3 DETECTOR FOR COMPTON IMAGING IN NUCLEAR MEDICINE

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Purpose: The purpose of this study is to explore the feasibility of using the Timepix3 CdTe detector as a Compton camera for Nuclear Medicine imaging applications. Current gamma camera technology relies on the use of a collimator to determine positional information for incident photons. Collimators, however, results in the attenuation of >99% of incident photons, requiring increased administered activities. A Compton camera is an imaging device that can determine the direction of gamma rays emitted by

radioisotopes based on the kinematics of Compton scattering. The development of such a Compton Camera design would negate the need for collimators, thus significantly reducing patient dose and potentially improving spatial resolution.

Material and methods: A high spatial, high contrast resolution Timepix3 device with a Cadmium Telluride (CdTe) sensor layer, was initially characterised in terms of energy resolution, detection efficiency and overall performance, including corrections for vertical positional determination. A Monte Carlo simulation of the Timepix3 detectors was developed using the EGSnrc Monte Carlo software and the results were validated with experimental data. Having established the properties of the detector, the methodology to identify the position and deposited energy of suitable photon events was developed to enable the determination of the corresponding Compton cones. Reconstruction of multiple such Compton cones will allow for location of the source to be determined. Compton imaging applications will thus be demonstrated and the functionality of the Timepix3 detector as a Compton camera explored.

Results: Single and multiple radioisotope point source arrangements will be presented, with the analysis demonstrating the capabilities of the use of the Timepix3 detector as a nuclear medicine Compton camera. The spatial resolution and sensitivity of the Compton camera will be quantified and related to conventional Nuclear Medicine technologies.

Conclusion: A preliminary evaluation of the Timepix3 indicates its potential for Compton Imaging applications. The continuation of this work will demonstrate the feasibility of the CdTe Timepix3 detector for basic nuclear medicine imaging applications without the need for a collimator.

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DEVELOPMENT OF A NOVEL PHANTOM TO CHARACTERISE PET/CT RECONSTRUCTION TECHNIQUES FOR THE ACCURATE QUANTIFICATION OF 18F-FLUORODEOXYGLUCOSE UPTAKE IN AORTA ATHEROSCLEROTIC INFLAMMATION

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Purpose: Atherosclerosis is a chronic inflammatory disease of the large and medium-sized arteries. 18F-Fluorodeoxyglucose (FDG) Positron Emission Tomography (PET) imaging permits the detection and quantification of early metabolic signs of atherosclerotic inflammation. However, accurate quantification of tracer uptake in the arterial vessel walls is challenging as the size of typical atherosclerotic lesions are below the resolution limits of PET imaging systems. Furthermore, the choice of PET image reconstruction greatly affects the outcome and reliability of the resulting quantitative measurements, particularly for small structures. This study aimed to investigate the impact of PET image reconstruction on the quantification accuracy of FDG uptake of atherosclerotic vascular inflammation.

Material and methods: A fillable 3D-printed resin phantom was designed and produced to closely replicate a range of dimensions (vessel wall-thicknesses of 2, 3.5 and 5 mm; vessel length 80 mm) and 18F activity distributions typically found in inflamed atherosclerotic aortas. The 3D-printed aorta phantoms were positioned centrally in a thorax-mimicking phantom and scanned using a Siemens Biograph PET/CT system. The acquired imaging datasets were reconstructed using a range of reconstruction parameters (matrix-size, iterations, point spread function (PSF), time of flight (TOF) and smoothing). From the reconstructed images, SUVmax, recovery coefficients (RC) and tissue-to-background ratios (TBR) were measured for phantom vessels of varying dimensions. Statistical testing was performed to identify if measurements of RC and TBR varied significantly with wall-thickness (lesion size) and reconstruction type (2-way ANOVA).

Results: A range of values for RCmax (0.35 to 1.02) and TBRmax (1.11 to 2.59) were measured in phantom vessels of varying lesion sizes that were filled with constant activity ratios. Both RCmax and TBRmax were shown to be statistically different between phantom vessels with different wall-thicknesses (two-way ANOVA, $p<0.05$). Only RCmax was shown to statistically differ between reconstruction types (two-way ANOVA, $p<0.05$). The most accurate activity recovery (RCmax=0.7) was obtained using the following reconstruction: TOF and PSF modelling, iterations=120, matrix=180 and smoothing=2mm. The most faithful measurement of TBRmax (=2.16) was obtained using the following reconstruction: TOF and PSF modelling, iterations=40, matrix=256 and smoothing=4.5mm.

Conclusion: The accuracy of PET quantification is dependent on lesion size and the chosen image reconstruction parameters. This study suggests that the calculation of TBRmax (normalising the measured wall activity by blood pool activity) may control for variations between reconstruction methods. Assessing quantification accuracy for a range of activity concentrations and ratios is ongoing and the results will be presented.

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A QUALITY MANAGEMENT SYSTEM FOR A NUCLEAR MEDICINE SERVICE

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Purpose: Nuclear Medicine is a Radiology modality that is highly regulated and regularly inspected from a radiation safety aspect. In Nuclear Medicine radioactive materials are ordered, delivered, prepared, dispensed, and administered to patients. As a result there are many layers of documentation, records and audits that are produced. A Quality Management System (QMS) was designed and developed In-House to address the demands for a busy Nuclear Medicine Service in Beaumont Hospital, Dublin. The aim of the QMS was to facilitate better document management, improve record management and to identify areas for improvement in our processes and procedures; this will help provide a safer and more efficient service for patients.

Material and methods: An In-house QMS was designed using Microsoft Share Point software. Microsoft Share Point is a web-based platform that is highly configurable and consists of document management and storage systems. The Nuclear Medicine Share Point site was integrated into the Hospitals Intranet home page, which make it easily accessible to the relevant authorised staff.

The IAEA's programme 'Quality Management Audits in Nuclear Medicine (QUANUM)' was used as a guiding framework for the design of the QMS.

The site contains a document management system for reviewing and approving SOPs, risk assessments, protocols and procedures for a range of topics and tasks.

The site contains a series of record libraries including:

- Equipment Management: Inventory and QA results
- Radiopharmacy Records: QA, Stock and Hygiene information
- Radiation Safety: Radioactive material and waste management, Security, Staff doses, Contamination and Spills and Staff Training.

Results: The QMS homepage consists of 12 sections each containing several sub-areas. The document and record libraries are integrated into these various sections for ease of access.

Nuclear Medicine QMS Sections Overview:

- Administration and Management

- Staff Training and Resource
- Quality System (QMS)
- Radiation Regulations and Safety
- Patient Radiation Protection
- Imaging Diagnostic Procedures
- Equipment Management (QA/QC)
- General Clinical Services
- Non-Diagnostic Procedures
- Computer Systems and Data Handling
- Radiopharmacy Operational Level
- General Radionuclide Therapy

Conclusions: The Nuclear Medicine QMS was designed and built with a quality and safety focus for both patients and staff. By developing a tailor made quality management system for the Nuclear Medicine Dept. it can be fully optimised for the local service needs. The QMS has been in use for over two years and has proven very beneficial at recent regulatory inspections.

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VENTILATION PERFUSION FUNCTIONAL DIFFERENCE IMAGES IN LUNG SPECT: A QUANTITATIVE IMPROVEMENT ON VENTILATION PERFUSION RATIO

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Purpose: Ventilation (V) perfusion (Q) SPECT imaging is important in the diagnostics of lung diseases such as pulmonary embolism, chronic obstructive pulmonary disease and recently in COVID-19 lung disease. The combined assessment of ventilation and perfusion permits the identification of classical mismatched and reverse mismatched defects, especially when these two parameters are combined in one measure as the ventilation perfusion ratio. Unfortunately, the ratio is only linear for ventilation and the scale is not symmetrical regarding classical and reversed mismatches. Small perfusion values give rise to artifacts. The scaled ventilation perfusion difference is presented as an alternative.

Material and methods: VQ SPECT was performed on patients with and without defects. Kr-81m was used as a ventilation tracer and MAA labelled with Tc-99m as a perfusion tracer. Ratio is defined as V/kQ and difference as V-kQ, where k is a scaling factor.

The iterative z-map method was applied for determining the scaling factor for ratio and difference images yielding a ratio of one and zero difference for matched ventilation and perfusion. Clinical thresholds for both the difference images are derived resulting in color maps of relevant mismatches with an absolute ratio larger than the arbitrary value of two.

Results: The relative difference is in second order proportional to the logarithm of the ratio, and has a scale going from -1 to +1, where -1 is perfusion only and +1 is ventilation only. Still the diagnostic value is hampered by the fact that areas with both low perfusion and ventilation can have high ratios. Therefore, the scaled (functional) difference is presented. Ratio, relative difference and scaled difference have been investigated in ten patients and are shown for three patients (one without defects).

Ratio and relative difference images suffer from a visual overexposure effect as is clearly visible for the respiratory tract. One patient with an area in a bottom lung with a very low perfusion and slightly decreased ventilation demonstrated overflow problems of the intensity in ratio images and an overestimation of the mismatched area in both the ratio and relative difference images.

Conclusions: While the relative ventilation perfusion-difference is a promising improvement of the ventilation-perfusion ratio, because it has a symmetrical scale and is bound on a closed domain, a better diagnostic value and functionality might be obtained by utilizing the scaled functional difference. The latter one seems superior to both the relative difference and ratio.

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COMPARISON OF TWO DOSIMETRY SYSTEMS FOR YTTRIUM-90 RADIONUCLIDE THERAPY

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Purpose: The aim of this work is to compare two treatment planning systems (TPS) owned by our hospital, RapidSphere (Varian Medical Systems) and Simplicity (Boston Scientific Corporation), for dosimetry of patients treated with Y-90 glass microspheres (Therasphere, BTG Inc.)

Material and methods: For four patients to be treated with Y-90 glass microspheres we calculated the optimized activity (A) to obtain a mean dose (D^mean) on the target volume (PTV) with both TPS.

We used the same structures (whole liver, PTV, normal tissue liver and external contour) in both TPS. We delineated them on the abdominal Technetium-99m-macroaggregated albumin (99mTc-MAA) SPECTCT-CT images used for patient evaluation prior to treatment. This structures has been defined in Simplicity. We exported them between TPS as a DICOM RT Structure.

The multi-compartment model was used In Simplicity. This TPS asks the operator to define an auxiliary volume where the activity is contained (perfused volume, PV). This PV was contoured over the emission images of 99mTc-MAA, by using a user defined threshold (T) of the maximum number of counts in the image. Different threshold values were used and activities were calculated in each case (A_Threshold^Simpli). In adition, a perfused volume was defined using the limits of the external contour. In contrast RapidSphere uses an anatomical contour as a reference to define the limits of the perfused activity. We have used the external contour (WB) as recommended by the system. The activity calculated in this case, A^Rapid, was compared with the activities planned in Simplicity. Activities were corrected for the lung shunt in both cases. Besides activities, we have obtained the mean doses and dose volume histograms (DVH) for the defined structures in both TPS.

Results: We have found averages differences in the calculated activities of: 65% for T=20%, 18% for T=1%, and 3% when we used the external contour for the perfused volume. Even in this last case we have found averages differences in doses to the liver normal tissue (D_NTL^mean) of 40%.

Conclusions: Threshold less than 5% should be used when defining the perfused volume with Simplicity. As for the RapidSphere, considering the whole external volume as the perfused volume does not take into account the image noise. The right calculation of the activity must be between both values. The reason for the differences found in D_NTL^mean, which do not correspond with the differences in calculated activities, should be studied carefully.

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A SCATTER CORRECTION METHOD FOR IMPROVED LUNG SHUNT FRACTION (LSF) ACCURACY: A MONTE CARLO STUDY FOR A RANGE OF GAMMA CAMERA SYSTEMS

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Purpose: Significant overestimation of the lung shunt fraction (LSF), as estimated from planar 99mTc-MAA imaging using the geometric mean method, has been well documented. Recently published EANM guidelines suggest that where the LSF <10%, the 'overestimated' LSF should be divided by a factor of 2.7. This factor of 2.7 has been established based on the average of factors ranging from 2 to 4 published by various studies. This range is likely to be related to the performance characteristics of the gamma cameras/collimators used and the imaging protocol employed. Previous work at our centre, performed on a single gamma camera type, has shown that the use of a scatter-window-based correction can significantly improve the LSF estimation accuracy to within 28% of the true LSF. Accordingly, the objective of this study was to investigate, through Monte Carlo simulations, whether utilising the scatter-correction-based approached developed in our centre is applicable to other gamma camera systems and, thus, would yield improvements in the LSF estimation accuracy.
Materials and methods: SIMIND Monte Carlo (MC) modelling software was used to simulate planar scintigraphy images of digital anatomical phantoms (RSD anthropomorphic thorax phantom and 4D XCAT Human Phantom) of a range of clinically relevant LSFs (0 – 25%) using a variety of gamma camera systems/published acquisition parameters. The main scanners modelled were the Siemens Symbia, Phillips Brightspace, GE NM gamma camera series, with new CZT crystal technology also modelled.
Results: This study will present an investigation on the impact of acquisition parameters and scatter correction on planar LSF estimation for a broad range of simulated LSFs imaged with the listed gamma camera systems. A comparison will be made between LSF estimations obtained through modelling and those LSF estimations cited in the literature. An optimised method of scatter correction, through the identification of appropriate acquisition and scatter windows, will then be established in order to improve LSF estimation accuracy for each system modelled.
Conclusions: The geometric mean method with an incorporated scatter correction and optimised acquisition parameters can significantly improve the accuracy of planar LSF estimation. Gamma camera specific corrections presented in this work will be easily implementable in any imaging centre.

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OPTIMIZATION OF SPECT/CT PROTOCOLS USING A RESOLUTION RECOVERY RECONSTRUCTION ALGORITHM

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Aim: Resolution recovery reconstruction methods in SPECT/CT imaging attempt to increase image quality to the standard protocol while shortening scan time or reducing the administered dose to the patient. This phantom study investigates the effects of reduced count statistics on SPECT image quality using an iterative reconstruction algorithm incorporating resolution recovery in order to optimize the acquisition time or the radiation dose.
Materials and methods: The acquisition of a Jaszczak Deluxe phantom was performed on a SPECT/CT scanner. The data were acquired using LEHR collimators, 128×128 matrix size, 120 views over 360 degrees rotation and body contour enabled. The phantom was filled with 99mTc water solution; 19mCi for full dose. For each dose level, variable acquisition times were also used. The acquired data have been reconstructed using the filtered back-projection (FBP), the ordered-subset expectation maximization (OSEM) and the OSEM with incorporating resolution recovery (OSEM-RR). Attenuation correction using CT data has been performed on the data. Therefore, a number of datasets with many combinations of algorithms and acquisition options were generated.
Results: The OSEM-RR improved uniformity up to 75% and maximum contrast up to 20% compared to the OSEM. Reducing the acquisition time up to one third of the recommended protocol, small differences have been observed in respect to the contrast, contrast to noise ratio and uniformity.
Conclusion: This phantom study suggests that for SPECT/CT imaging, the use of iterative reconstruction incorporating resolution recovery can provide high quality images even for low count statistics. However, the use of resolution recovery needs to be further optimised as the suppression of noise may result in artefacts.

EPOSTER ABSTRACTS – PROFESSIONAL MATTERS

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MEDICAL PHYSICS PRACTICE IN DEVELOPING COUNTRIES: HOW MEDICAL PHYSICISTS CAN BRIDGE THE GAP?

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Purpose: There has been a strong emphasis on the role of medical physicists in centred-patient care and precision medicine in major conferences in medical physics and recent guidelines published by western scientific associations and professional societies (EFOMP, AAPM, RSNA, etc). Several rigorous initiatives have been undertaken to review and modernise medical physics education and training with the most recent revisions focusing on the effective introduction of artificial intelligence and inclusion of management and leadership modules. Intensive and specialised medical physics education programmes were developed and established in the developed countries during the last 2 decades. This is, unfortunately, still not the case in developing countries at the exception of limited initiatives by academics in large universities. The major aim of this educational abstract is to, constructively, discuss the major challenges and identify effective pathways to bridge the gap between the practice of medical physics in western and developing countries.
Methods: The rigor and relevance of medical physics science to many clinical practices is unquestionable and is recognised to be a key driver towards patient-centred care in the developed countries. Despite the availability of state-of-the-art imaging and radiation therapy equipment and radioisotope production centres in modern healthcare facilities in developing countries, the duties and responsibilities of medical physicists are limited to quality assurance and quality control programmes, education and training junior staff, procurement of equipment, assessment of radiation shielding and radiation protection. The involvement in medical laser safety practice, multi-centre clinical trials, radiology and radiotherapy

quality management programmes is key to reach western standards. It is worth mentioning that the essential role of medical physicists is highly underestimated by most healthcare professionals, high managers and advisers to decision makers. A wider involvement of medical physicists in multi-disciplinary clinical research projects and in the selection of maintenance contracts is a high requirement in developing countries given the nature local economies and working culture.

Conclusion and recommendations: Imaging and radiation therapy technology required a wider and stronger involvement of medical physicists in several clinical practices. Ministries of higher education and health should setup joint expert committees to: (i) establish national regulatory bodies and develop training programs involving board-registered medical physicists; (ii) define a clear career progression pathway.

Medical physicists duties should include: (i) involvement in the planning, design, introduction and assessment of diagnostic and therapeutic applications; (ii) participation in income generation and cost-saving and improvement programs to support continuous professional development.

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EFFECT OF STOMACH SIZE ON ORGAN AT RISK IN PANCREAS STEREOTACTIC BODY RADIOTHERAPY

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Purpose: In clinical practice of pancreas stereotactic body radiotherapy (SBRT), organ at risk (OAR) should be carefully planned. Therefore, we conducted a simulation study to examine the effect of gastric size on the dose of OAR when performing pancreatic SBRT.

Material and methods: Twenty-five cases were included in this simulation study. Pancreatic head cancer was contoured as a 2 cm-sized pseudo-tumor as gross target volume (GTV), and pancreatic body cancer was also contoured as a 2 cm-sized pseudo-tumor as GTV. The stomach, pancreas, small intestine, liver, kidneys, and spinal cord were set as OARs. The prescription dose for planning target volume (PTV) was 40 Gy/5fx, and the dose limit for OAR was settled. The DX (the dose to X% of the Organ at Risks [OARs] volume) at X values of 0.1, 5.0, and 10.0 cc and VX (the percentage of the OARs volume that received more than X Gy) were recorded.

Results: Regarding the irradiation dose to pancreatic body tumors, the size of the stomach is positively correlated to the dose to the stomach of D10cc (correlation coefficient (r) = 0.5516). The r between the irradiation dose to the pancreatic head tumor and the size of the stomach was 0.3499.

There was a positive correlation between gastric size and dose at the head and body of the pancreas (Pancreas head D10cc: r = 0.3979, Pancreatic body D10cc: r = 0.3209). The larger the stomach, the larger the dose to the stomach.

Conclusion: When using the pancreatic SBRT, the dose of OAR depends on the size of the stomach. Stomach shrinkage is useful because reducing the dose to the stomach and pancreas can be achieved by shrinking the stomach.

EPOSTER ABSTRACTS – RP

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QUALITY ASSURANCE OF CYLINDRICAL CHAMBERS BY RADIOACTIVE CHECK DEVICE

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Purpose: Stability check of ionization chamber can be done by radioactive check device (RCD) or two independent dosimetry system and results should fall within appropriate limits set by the IEC 60731.

Material and methods: RCD used in the study is manufactured by Iba Dosimetry GmbH/Eckert Ziegler, Germany. It contains Strontium 90 isotope, with initial activity of ~30 MBq, and with half-life of 28.7 years. Stated dose rate at 10cm distance was at that time <1μSv/h.

In total 6 farmer type chambers were investigated. The oldest one was 17 years old and most recent chambers were purchased in 2016. All chambers were FC-65 G manufactured by Iba Dosimetry and biannually calibrated in Serbian SSDL. We investigated: short-term repeatability, long term reproducibility, angular response of chamber placed in a holder of radioactive check device and after that in 6 MV beam in water phantom, the amount of background radiation by survey meter AtomtexAT 1117and its influence on measurements, post-irradiation leakage.All results were corrected for temperature, pressure and decay.

Results: Decay factor and activity as of today were determined by formula. All results were compared to IEC limits.

The average leakage current was 0.017 pA (0.01% versus 0.5%IEC limit). Voltage applied was kept between 299V and 300V (difference 0.3%), with limit to variation of voltages 1% according to IEC.

Stabilization time prior to use was 15 minutes under voltage +300V applied, after that chamber was continuously irradiated for 20 minutes and reading difference was less than 0.5% (limit by IEC).

Short term repeatability was ranging from 0.19% to 0.25% (limit ±0.3%).

Linearity of dose with time/accumulated dose stability was 0.03% (limit 1%). Post-irradiation leakage was also measured and current decreased to 0.3% of the reading measured during 10 min irradiation (1% limit).

Long term reproducibility/stability was less than 0.2% (limit 0.5%).

Influence of angle of chamber (angular response) in radioactive check device was checked and averaged at 0.9% in RCD for all chambers.

The same measurement was conducted in MV beam in water.

Conclusion: Orientation of a chamber should be always the same, as random insertion into the RCD may influence the outcome of measurement due to possible angular dependence of a chamber reading in the RCD. Other tests have proven that chambers are correctly functioning, according to the standards provided by IEC 60731.

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MODELING OF PRIOR KNOWLEDGE IN VMAT TREATMENT PLANNING –CLINICAL VALIDATION

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Purpose: Treatment planning of advanced techniques requires deeper knowledge of functions of the treatment planning system. Number of patient to be treated by VMAT techniques is rapidly increasing, while number of experienced treatment planners does not. The aim of the work was to develop a model from the existing database of treatment plans, and test them against the cases the model new clinical treatment plans, to enable faster treatment planning.
Material and methods: The treatment planning system Monaco was used for VMAT treatment planning of gynecological patients. The model was developed from existing database of treatment plans. The generation of a model was done via Python programming language. The following parameters were observed: beam parameters (energy, gantry angles and number of arcs, collimation, MU number), cost functions for each organ at risk: rectum, bladder, femoral heads, external contour, small bowels. Homogeneity index was compared for both type of treatment plans. For the purpose of model testing, additional 30 new patient plans were selected and compared to model based treatment plans.
Results: There were in total 109 treatment plans which served for model development. The plans were generated during first six years after clinical implementation of VMAT. The plans were created by ten different medical physicists, and reviewed by radiation oncologist. The model consisted of 2 arc (4 rotations) 10 MV beam. The constraints to the target were met in all treatment plans both clinical and model based, evaluated by D50, D98, D95, D0 and D2. The OAR doses were evaluated by maximum and mean doses. Number of MUs and plan homogeneity was evaluated. Significant difference is found in small bowels, due to contouring differences.
Conclusion: To facilitate treatment planning, the model was developed and tested.In manual treatment planning each decision is based on the experience and current knowledge of a planner, while model based treatment planning improves efficiency, quality of plan, and allows planning to less experienced planner. The model is comprised of representative statistical data from clinically accepted treatment plans and only additional fine tuning of the model-based treatment plan was needed. The final decision of experienced planner remains the parameter for clinical acceptability of a plan, however, per treatment plan at least 3-5 hours is saved. The model developed is clinically tested and confirmed as baseline treatment plan and showed no inferiority to treatment plan generated by qualified medical physicist.

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RECURRENT CT SCANS IN A GREEK TERTIARY HOSPITAL: A PRELIMINARY STUDY

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Purpose: As Computed Tomography is a high-dose modality, attention should be paid to the patients having recurrent CT exams who may receive cumulated effective dose (CED) of 100 mSv or higher. This study was a first attempt to record and analyze data from the patients who had recurrent CT exams in a Greek tertiary hospital.
Material and methods: All CT adult examinations of the head and trunk performed at "Hippokratio" Hospital of Thessaloniki during the first semester of 2021 were included. Effective doses were calculated using the dose-length-product values (DLP) and ImPACT CT Patient Dosimetry Calculator®.
Results: In total, 4633 CT exams were performed during the first semester of 2021 to 3623 adult patients. Multiple CT exams were received by 654 patients (18%). The majority of those patients (67%) had 2 CT exams and 35 of them (5%) had more than 4 CT exams. The maximum number of CT exams per patient was 11. The median age was 70 years. The majority of the multiple scans (47%) were of the trunk, 42% of the head region and 11% of both head and trunk (whole-body scan). Patients older than 70 years had mainly scans of the head whereas the younger patients had mainly scans of the trunk ($p<0.001$). The median total DLP and cumulative effective dose were 3076 mGy*cm and 27 mSv respectively.
There were 54 multiple scans patients who received more than 100 mSv. The majority (67%) were younger than 70 years old. The primary clinical indications were mostly chronic disease (26%), oncologic disease (17%) and trauma patients (15%). Most of the younger patients were referred for chronic diseases whereas the older for oncologic diseases or abdominal pain. For more than 4 scans the probability of having CED>100mSv was significantly higher ($p<0.001$).
A notification level of 5700 mGy*cm and 7000 mGy*cm were estimated for the trunk and whole-body scans respectively, based on the linear correlation between DLP and effective dose ($R2=0.61$) for avoiding doses exceeding 100 mSv.
Conclusions: The percentage of patients receiving high CED from recurrent CT examinations was small (8%) but not negligible. Notification values of 5700 mGy*cm and 7000 mGy*cm DLP for body and whole-body scans were implemented to the CT machine protocols. Special attention should be drawn to patients younger than 70 years old, to those referred for chronic diseases and to those who used to have more than 4 CT scans of the trunk.

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FUNDAMENTAL SOLUTION FOR INTEGRATION OF C-ARM X-RAY DEVICE WITH RELATED CEILING-SUSPENDED PROTECTIVE SCREEN

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Considering scatter radiation, the proper positioning of of the ceiling suspended screen during interventional radiology procedures, from start to finish, is very important for occupational dose reduction and control. The essence of the solution is linking the C-arm X-ray device and the screen into single system and thus enabling automatic control repositioning of the screen, considering initial repositioning and potential adjustments throughout intervention, medical needs and all general safety and security conditions. The solution passed both technical and medical consensus, as well as patent examination. A relevant simulation was made, which explains all operational principles.

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FRENCH NATIONAL DIAGNOSTIC REFERENCE LEVELS IN DIGITAL MAMMOGRAPHY AND DIGITAL BREAST TOMOSYNTHESIS

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Purpose: The purpose of this study is to assess the mean glandular doses delivered during digital mammography (DM) and digital breast tomosynthesis (DBT) examinations in France in order to set national diagnostic reference levels (DRLs).

Material and methods: Data from 77 DM units and 44 DBT units have been collected across France, considering craniocaudal (CC) and mediolateral oblique (MLO) views. In DM only screening examinations were included in the study. In DBT all indications were included. Mean glandular doses (MGD) displayed by the systems and compressed breast thicknesses (CBT) were analysed on, at least, 60 consecutive patient examinations per unit.

Results: Data were received for 5300 DM examinations and 3009 DBT examinations.

MGDs in DBT were around 35% higher than in DM. For oblique views, values of the 75th percentile of the MGD per installation were 1.7 mGy in DM vs. 2.3 mGy in DBT, and values of the 50th percentile were 1.5 mGy vs. 1.8 mGy, with a median CBT of 56 mm in DM and 57 mm in DBT. The results vary greatly depending on the manufacturer and on the compressed breast thickness.

Conclusions: The IRSN recommends setting the French national DRL at 1.7 mGy in DM and 2.3 mGy in DBT regardless of the compressed breast thickness and view (CC or MLO).

The IRSN recommends that each French facility collects every 3 years DM and DBT MGDs and compressed breast thicknesses for at least 50 patients per installation, as suggested by the ICRP publication 135, to compare their local DRLs to the national DRLs. While doing this comparison, facilities should take into account their median compressed breast thicknesses, which could differ from those of this study.

For its part, IRSN will analyse, every three years, the MGD delivered in DM and DBT at the national level taking into account the compressed breast thicknesses.

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ADMINISTERED ACTIVITY AND FLUIDS INTAKE AS PREDICTORS OF SHORTER ISOLATION TIME FOR LOW RISK PAPILLARY THYROID CANCER PATIENTS UNDERGOING RADIOACTIVE IODINE THERAPY

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Objectives: Patient upon admission in the isolation ward to be treated with radioactive iodine for thyroid cancer post ablation are instructed to drink plenty of water in order to shorten the length of stay at the hospital and to be discharged in a timely manner. Physiological clearance of Iodine-131 from will differentiated thyroid cancer (DTC) patients is complex with many factors affecting its normal conduct leading to altered excretory function behaviors. The aim of the study was to examine few factors potentially related to radioactive iodine clearance from patients with DTC admitted to our medical Centre.

Methods: Logistic regression (LR) was used to analyze the multivariable data and to propose a model (LRM) that can predict the probability of the patient to be isolated for shorter time taking into account the administered activity in [MBq] and the total volume in [ml] of fluids consumed during his stay in the hospital. Two hundred and eighteen patients are included in this study.

Results: The propose logistic regression model is: Log (odds) = -3.9931+ 0.0007*(fluids intake in [ml])+ .0011*(administered activity in [MBq]). This model has an area under the ROC curve of 0.70 and false positive rate of 0.34 or (specificity= .66) and true positive rate or (sensitivity) of 0.68. The model may help organizing the ward assignment and allows better planed radiation protection aspects of the procedure.

Conclusions: The presented method can be used in to analyze variables related to a binary outcome like short or long isolation time and also in predicting the probability of the outcome before the start of the procedure once we know the administered activity and the amount of fluids that the patients will consume during his or her stay in the ward.

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COMMISSIONING OF ECLIPSE TPS FOR VMAT TREATMENTS IN HALCYON

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Purpose: The purpose of this work is to describe the adopted program for commissioning of Eclipse TPS for VMAT treatments in an Halcyon linac recently installed at our institution.

Material and methods: The established program involved three steps:

1) the validation of the beam model pre-configured in Eclipse TPS v16.1, through extensive beam measurements using the SunNuclear 3D scanner with Halcyon kit option and the corresponding dose calculations through 1D gamma analysis using an in-house software tool;

2) a set of spatial and geometric tests to assess CT images properties and the integrity of the delineated structures, including the evaluation of the HU values, dimensions and image acquisition orientation as well as of the localization and volume of the structures;

3) VMAT plans verification through end-to-end tests adapting the AAPM TG-119 test cases. Plan verification was performed using an independent dose calculation software (DoseCheck), as well as ionization chamber, EBT3 film, portal dosimetry and ArcCheck measurements. Planned and measured dose distributions were compared using global gamma analysis, as per AAPM TG-119 recommendations.

Results: Differences between measured and calculated profiles and PDD for the various field sizes were mostly compliant with 1%/1mm gamma criteria. A criteria of 2%/2mm had however to be considered in the penumbra region, as well as in a limited area outside the field for large field sizes (>20x20cm2). The calculated and measured output factors were within less than 1% agreement, except for 1x1cm2 field with a discrepancy of 1.5%. MLC transmission and dosimetric leaf gap values matched those of the standard configuration.

The results of the spatial and geometric CT/structure tests revealed that Eclipse tends to underestimate the volume of the imported contours, which has a greater impact in small structures.

For the VMAT test cases, all plans met the tolerances established in TG-119 report, regardless the considered QA method.

Conclusions: A comprehensive quality assurance program for Eclipse TPS for VMAT treatments in Halcyon has been established. It proved to comply with the international recommendations concerning commissioning. It will further be used for periodic QA of the Eclipse TPS at our department.

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EXPOSURE INDEX MONITORING; A FIRST EXPERIENCE IN THE OPTIMIZATION PROCESS

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Purpose: This work aims to assess the correct setup and usage of a novel x-ray unit recently acquired by our Institution in terms of optimization of x-ray dose to the systems' digital detectors.
Material and methods: We connect the system to our dose monitoring system. The x-ray unit produces a DICOM Radiation Dose Structured Report in which for every irradiation event we can access the Exposure Index EI (measure of the detector response in the relevant image region), the Target Exposure Index EIT (the target value used to calculate the Deviation Index) and the Deviation Index DI (a scaled representation of the difference of the Exposure Index compared to the Target Exposure Index). We focused our analysis on the DI - defined as DI=10logf_0(EI/EIT) – and analysed its values' distribution; we used AAPM TG 116 action levels as guidelines to see if our detectors are receiving the proper amount of radiation with respect to the exam type and patient's physique.
Results: The overall mean of DI is 0.98, the 1st quartile is -1.1 and 3rd quartile is 2.9. The percentage of exposures with DI between -0.5 and 0.5 is just 13.8%. Almost 25% of exposures is above DI=3 (i.e.: 2 times the target exposure). With those findings, we inspected the unit and realized that most of the examinations was without automatic exposure control with some parameters not properly set. Also, we found that for some exams the radiographers used a detector plate without the proper shell, while the system's current was set expecting the presence of the shell's attenuation grid.
Conclusions: We started monitoring the exposure index and the deviation index DI for a recently acquired x-ray unit. The analysis of DI was useful to find improperly configured parameters and incorrect practices to be corrected. We believe that DI monitoring is potentially a very useful tool for the process of optimization.

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RELATIONSHIP BETWEEN THE AMOUNT OF FLUID CONSUMED AND THE DISCHARGE TIME OF THYROID CANCER PATIENTS UNDERGOING RADIOACTIVE IODINE THERAPY

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National regulations stipulate that patients administered with radiopharmaceuticals having activities of more than 1111 MBq to be admitted to the hospital in specially designed rooms to receive the therapeutic dose, this is the common case of radioactive iodine therapy (RAIT). The patient is discharged from the hospital by the radiation protection section staff once the remaining activity in the patient body falls below 1111 MBq; in our hospital the patient is released when the activity is below 400 MBq.
Upon admission to the isolation ward the patients are instructed to drink plenty of water and other fluids in order to increase the I-131 release from their bodies through urine and therefore reduce the duration of their isolation time in the hospital. The aim of the work was to establish a relationship between the total amount of fluids consumed by the patient in [ml] and the discharge time in [Hrs].
The patients in this study are all patient with papillary thyroid cancer (PTC) and have no metastatic disease (absence of distant metastasis) and have underwent total thyroidectomy.
We report the results of 200 patients treated between 2019 and 2021 in our tertiary care medical center. Results show no direct correlation between the amount of fluids consumed and the discharge time, we recommend the study of other factors that may have more significant correlation with the discharge time than simple consumption of fluids.

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DIAGNOSTIC REFERENCE LEVELS ANALYSIS WITH AN AUTOMATED PYTHON CODE

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Purpose: Diagnostic reference levels (DRLs) are useful to verify that the diagnostic protocols of the x-ray equipment under our management optimizes the dose delivered to the patient, achieving a correct image quality. To study these DRLs, we work with an extensive amount of data that must fulfill certain conditions like patient age, clinical protocol, body part location, etc. For this reason, determining DRLs in any non-small institution may be time-consuming. Henceforth, we have developed an automated code based on Python to analyze the data and to obtain a compendium of the results.
Material and methods: The programming language used is Python because of its versatility. The module Pandas is used to deal with large data by reducing memory usage and ultimately improving computational efficiency. The code can be adapted to be fed with several files containing a single x-ray device data, or a single file containing all data. It automatically detects the x-ray modality (CT, conventional radiology or mammography) attending to the dose parameter contained in the file (CTDI or DLP, DAP or MGD). Various filters are applied to discard data such as:

- Non-clinical protocols (topograms, scouts, calibration…).
- Age range.
- Entries with empty critical data (e.g. dose parameter).
- Less abundant protocols (e.g. less than 1% of the total on each device).

The remaining protocols are grouped by location, considering the resemblance of the protocol name with body locations (head or brain with cranial location, lung or pulmonary with thorax location, …). To accomplish this, we use the concept of Levenshtein distance, which counts the number of letter changes (substitution, insertion or deletion) to convert one word into the other. Once these are grouped by location, a statistical analysis is performed, and the median dose parameter is computed to compare with the dose reference level.
Results: The main advancement of this automated process is to classify the different diagnostic protocols with their corresponding body locations. These protocols are named diversely in different devices even in the same institution. Thanks to the algorithm based on Levenshtein distance, the majority of the protocols are correctly identified, although the work to enhance the performance is still in progress.
Conclusions: Python combined with Pandas is a very versatile tool to work with large amounts of data. With these kinds of homemade programs, European institutions may save a lot of time in the future when setting their DRLs.

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HISTORICAL PET/CT STAFF DOSE REVIEW AND COMPARISON TO THEORETICAL VALUES

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Purpose: PETCT is traditionally known as a high occupational dose modality. As a consequence, this can discourage radiology staff from specialising in this dynamic and unique area. This review of occupational dose records aims to evaluate practical radiation protection in PET/CT and compare actual outcomes to theoretical projections. The staff dose records span the period from the inception of the centre to the scanner replacement 16 years later .

Material and methods: Analysis of key performance metrics from the routine staff radiation protection records can yield some interesting and important results. Staff routinely record whole body dose per day, as logged by calibrated EPDs, this is collected and reviewed by medical physics each month. This data can then be tracked alongside patient dose parameters to give dose metrics which allow analysis of radiation protection practice by staff. EPD dosimetry records were confirmed against standard monthly TLD reports.

Results: Staff categorisation in PET/CT, across 16 years of operation encompassing 59 unique staff, has resulted in a total of two distinct staff members being categorised as category B based on whole body dose measurements (as per SI 30, 2019). One of these staff members has been categorised 15 times as a result of workload while the other was categorised only once. No members of staff were designated as category A. The radiographer dose per patient was found to vary based on the number of assigned radiography staff, and not the total number of patients.

Conclusions: Staff dose in PET/CT can be optimised and remain low when a multidisciplinary approach is employed. A well designed PET/CT centre allowing optimal workflow allows a robust high throughput service to be delivered without impacting on occupational dose.

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MONTE-CARLO MODELLING OF HP(10) IN A WOMED TREATMENT ROOM TO INFORM RADIATION RISK ASSESSMENTS

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Aims: Current Irish radiation protection legislation S.I.30 requires hospitals to have radiation risk assessments (RRA's) that include detailed estimates of potential doses that could occur due to unintended exposures. However, current methods to estimate these dose values are typically rough approximations. This project developed a quantitative model which could calculate the $H_p(10)$ values in a superficial treatment room to inform the RRA's for the newly commissioned WOmed unit.

Methods: The model was a Monte-Carlo model created using Geant4-based MC toolkit, TOol for PArticle Simulation (TOPAS) [1,2]. The method involved three major steps: (1) $H_p(10)$ phantom was created using an ICRU slab as defined in ICRU report 47 [3]; (2) the fluence in the $H_p(10)$ phantom was scored; (3) the fluence was then converted into $H_p(10)$ values using conversion coefficients as set out by Pelliccioni [4]. The spectrum files from the WOmed unit for the 100 kV, 120 kV, 150 kV and 200 kV energies were input into the model, and model was then used to calculate the $H_p(10)$ values at different locations in the room. The model was verified by taking measurements using Electronic Personal Dosimeter (EPD) calibrated to measure $H_p(10)$. Then, the model was applied to a range of clinical scenarios to calculate a risk rating for those scenarios.

Results: Measurements of the $H_p(10)$ value were taken for a beam-on time of 60 seconds for an 8×10 cm applicator, for the 100, 120, 150 and 200 kV beams. These measurements were compared to the values given by the model, with the Hp(10) values predicted by the model being within 32% of the measured values for the 100 kV beam, within 17% for the 120 kV beam, 17% for the 150 kV beam and 23.5% for the 200 kV beam. The model was applied to a range of clinical scenarios, an example of which was for an exposed person 50 cm from the patient's position for the duration of a 4 Gy treatment fraction. The $H_p(10)$ value for this situation was found to be 1.31± 0.3 μSv. This value was then used to calculate a risk rating of 3 for the scenario, which could then be used to update the RRA.

Conclusion: A model was created which can be used to quantify radiation exposure for scenarios of potential unintended exposures. Risk assessments can be dynamically adapted over time using the model to reflect any changes in the controlled area, as recommended by the regulatory body, the EPA. The model represents a valuable tool for radiation protection advisers, as it will allow them to create more quantitative radiation risk assessments.

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A TASK BASED DOSIMETRIC ASSESSMENT OF INTERVENTIONAL CARDIOLOGISTS BEHAVIOUR USING A REAL TIME ACTIVE DOSIMETRY SYSTEM

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Purpose: The eye dose limits specified in EU basic safety statement 59/2013 (150mSv – 20mSv per annum) presents an increased challenge for interventional cardiologists. This change in the eye dose limit has the potential to limit the number of procedures being carried out by these highly skilled healthcare workers. An increased awareness of radiation safety, combined with this change in the eye dose limits, have recently lead to the optimisation of the imaging protocols within a busy cardiology department at the Mater Private Hospital. The aims of this study was to assess the effects of optimisation on occupational dose within the cardiac catheterisation laboratories.

Material and methods: A simulated phantom study was conducted to assess the effects table and overhead shielding and c-arm angulation had on the peak dose rates and the equivalent dose at the collar of the operator. A real-time study was then carried out using real-time dosimeters (RaySafe i2 Active Dosimeters, RaySafe, Sweden) to assess the cumulative dose per task/c-arm angle received by the cardiologist during the examination. In addition a patient dose survey was completed for the periods pre and post

optimisation, to determine if a statistically significant difference in mean patient DAP (Dose Area Product) existed between the two periods (n= 50 for both cohorts).
Results: A reduction in frame rate from 10 to 7.5 frames per second (fps) resulted in a reduction in peak dose rate by 14.32%. The Left Ventricle Function (LVF) acquisition protocol was reduced from 30 to 7.5 fps which produced a reduction of 65.33%. The RaySafe i2 Active dosimeters were observed to be consistent in terms of their relative response to the change in frame rate. However, their measurement of absolute dose was shown to vary notably in comparison to the RaySafe X2 survey meter. Through optimising the imaging protocols, it was also noted that a statistically significant reduction in mean patient DAP was noted between the periods pre and post-optimisation ($t98 = 27.01$, $P < 0.001$).
Conclusions: It can be observed from the findings that a reduction in operator exposure and also patient dose has been achieved through the optimisation of procedural protocols by the cardiology department of the Mater Private Hospital.

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ASSESSMENT OF THE CT SCAN AND CBCT DOSES FOR DIFFERENT RADIOTHERAPY PROTOCOLS
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Purpose: The aim of this study was to evaluate our clinics protocols for CT and cone beam computed tomography (CBCT) imaging by calculating CT dose index (CTDI) and dose length product (DLP) for 2 CT scanners (GE healthcare CT 590 RT and Somatom definition edge); as well as CTDI, DLP and cone beam dose index (CBDI) for 5 radiotherapy accelerators (2 Varian True beam, 2 Halcyon and Clinac IX) using corresponding radiotherapy protocols (pelvis, head, thorax and pediatric) in order to estimate CT and CBCT doses that patients receive from imaging. Normalized effective dose per DLP was estimated for standard patients of diverse age over different body regions.
Materials and methods: The measurements on CT scanners and accelerators were carried out with Magic max solution that consists of: 3 part PMMA CT phantom (body, head/pediatric body and pediatric head), ionization chamber DCT10-MM and Magic max universal basic unit.
Results: Clinac IX gave the highest overall values for CTDI, CBDI and effective dose values across all the applied protocols, while the lowest recorded doses were for the two Halcyon machines.
CTDI, CBDI, nCTDIw and nCBDIw differences were most notable for head and pediatric head protocol, where Clinac delivered approximately 2-3 times higher doses than the other machines.
The difference in effective CBCT doses between Clinac IX and Halcyon is most remarkable for pelvis protocol, with Clinac delivering approximately 2 times larger doses for given region. Effective doses for head and pediatric regions were comparable, for both TrueBeams and Halcyons, with Clinac giving insignificantly higher doses than the two.
Conclusions: Estimated effective dose values for certain localizations were higher than expected, while CBCT doses were in accordance with the Varian standardized protocols. This led to detailed revision of currently employed CT protocols for given regions, with emphasis on using lower current settings in the future, without losing focus on preserving the image quality. The next steps should be to include patient size correction to refine dose estimate. CTDI calculations are likely enough for quality assurance (QA) and optimization of imaging dose.

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RADIATION EXPOSURE TO TOE OPERATORS DURING CARDIAC INTERVENTIONS
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Purpose: Transoesophageal Echocardiography (TOE) Operators provide vital imaging during structural cardiac intervention procedures. Due to the nature of the ultrasound technique and the fact that ultrasound imaging is required while fluoroscopy screening, they are in close proximity to the patient head and are liable to receive high levels of scattered radiation. This study compares instantaneous dose rates (IDRs) received by Cardiologists and TOE Operators in a busy interventional cardiac catheterisation laboratory to help inform radiation protection requirements for this cohort. Currently an under-table lead shield (0.5mm lead) and ceiling shield (0.5mm lead equivalent), located on patient right are used to provide additional protection to the Cardiologist.
Material and methods: Instantaneous dose rate measurements were recorded using a Raysafe X2 Survey meter ($H^*(10)$ rate, 0 µSv/hr – 150 mSv/h±10%) during structural cardiac interventional procedures. Measurements were recorded for the Cardiologist and TOE operator at knee, abdomen and eye height and averaged for the different procedures and c-arm angles.
Results: IDR measurements were recorded for Cardiologists and TOE operators during PFO (patent foramen ovale) closures and LAA (Left atrial appendage) cardiac interventions. The most common projections were posteroanterior (PA) and right anterior oblique (RAO). The TOE Operator received mean IDR values to their knees that were twice as high as the Cardiologist (391 µSv/hr compared to 175 µSv/hr). Comparable IDR measurements were recorded at abdomen height for both staff (231 µSv/hr Cardiologist, 220 µSv/hr TOE operator) and for eyes (124 µSv/hr Cardiologist, 91 µSv/hr TOE Operator). RAO projections resulted in 2-3 times higher IDRs to the TOE Operator for eye, abdomen and knee measurements compared to the Cardiologist.
Conclusions: TOE Operators receive higher radiation dose rates to their lower extremities compared to Cardiologists during structural cardiac intervention procedures. Both staff received comparable IDRs to their abdomen and eyes. RAO projections resulted in higher doses to the TOE Operator compared to the Cardiologist. These measurements will be used to inform clinical radiation protection practice to reduce occupational dose to TOE Operators.

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USE OF A NOVEL RADIATION PROTECTION DEVICE TO REDUCE STAFF RADIATION EXPOSURE IN CATH LAB
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Purpose: The Rampart is marketed as a fully adjustable, portable radiation protection device with the ability to protect multiple people and provide multiple vascular access points. The acrylic panels provide 1mm Pb equivalent shielding and the soft shielding provides 0.5 mm Pb equivalent. The aim of the device is to remove the requirement for lead aprons for operators in Cath Lab. This device was employed for one week in two of our Cath Labs and instantaneous dose rate (IDR) measurements were recorded at various staff positions and around the device. Subsequent measurements were made for the same staff positions without the device to assess its radiation protection performance.

Material and methods: IDR measurements were recorded using a Raysafe X2 Survey meter (H*(10) rate, 0 μSv/hr – 150 mSv/h±10%) during interventional cardiac procedures. Measurements were made for the Cardiologist (Operator 1) closest to the patient head, Operator 2 assisting the Cardiologist, Radiographer, circulating nurse (positioned behind Operator 1 at a trolley), TOE operator (based at the patient head on the opposite side of the table to the cardiologist) for structural cardiac procedures and anaesthetist. IDRs were measured at body height at each staff position and eye and knee height for Operator 1 and the circulating nurse. These were then averaged for the different procedures and c-arm angles with and without the Rampart in place.
Results: The system was installed close to Operator 1. Initial set-up of the system by a trained company representative took 5 minutes including attaching an additional extended lower table shield and using small lead shields to close any gaps between the table and lower lead curtain. Collisions occurred frequently between the Rampart and C-arm during coronary angiograms but fewer adjustments were required for PCIs and structural cardiac procedures.
A dose reduction factor (DRF) comparing average IDRs with and without the Rampart showed enhanced protection for Operator 1's eyes (DRF of 43) and knees (DRF of 9). The circulating nurse's body measurements also showed a DRF of 34 with the Rampart in place. The remaining staff had DRFs or 3 or less.
Conclusions: The Rampart system does offer additional radiation protection to those staff closest to the device, Operator 1 and the circulating nurse, but did not give enhanced protection to the other staff members present. The device is relatively easy to use and more suited to procedures involving minimal c-arm movements.

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BLOOD MICROSTAMPING: AN ALTERNATIVE BLOOD COLLECTION METHOD FOR BLOOD AND BONE MARROW DOSIMETRY FOR THYROID CANCER PATIENTS

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Purpose: Radioactive iodine (I-131) is used for remnant ablation of differentiated thyroid cancer (DTC). Personalising I-131 treatment is of therapeutically advantageous, however, when pretherapeutic dosimetry measurements are not possible, during-therapy dosimetry can be performed to retrospectively assess critical organs' absorbed doses (required by legislation, Euratom 2013/59), and can be used as a basis for planning future treatment. The European Association of Nuclear Medicine (EANM) dosimetry protocol, which ensures that a safe limit to the critical organs is not exceeded, requires multiple venous blood samples and whole body measurements; however, collecting blood samples from patients administered with high I-131 activities increases staff radiation exposures. Capillary (finger-prick) blood collection is proven to be a less invasive and less stressful alternative to venous or arterial blood collection, while also reducing collection time, increasing repeatability, not requiring post-collection processing, facilitating easier transport and storage, and lowering biohazard risks. This work proposed to establish whether venous blood withdrawal, as suggested by the EANM dosimetry protocol, may be replaced by a finger-prick blood sampling method, while maintaining the 5% acceptable uncertainty of counts required by the protocol.
Material and methods: Blood samples from patients referred to the Nuclear Medicine department at St James's hospital, Dublin, for I-131 therapeutic ablation, or for thyroid cancer surveillance scanning, were measured using a NaI well counter. The finger-prick and the standard venous-blood by venepuncture sampling techniques were evaluated for a range of factors, the main factors including blood type and its geometry.
Results: 30 blood samples (finger prick and standard venepuncture) were taken at various time points (2–191.9 hours) post administering of I-131 activities (200MBq, n=2; 3.9±0.1GBq, n=28) from 16 patients. There was no significant difference between capillary-blood drop and venous-blood drop count-rates (-0.98±4.31%, p=0.223) and no significant difference between 0.03-ml capillary-blood drop and venous-blood samples of 1.0-ml after volume correction (-1.76±8.86%, p=0.286). The finger-prick sampling took 50% less time than venepuncture sampling (p<0.001) and, hence, led to less radiation exposure to staff. The 1-ml venous-blood count-rate, required by the EANM protocol, can be estimated using the finger-prick blood count-rate with 94.5% predictability.
Conclusion: The study proves the accuracy of finger-prick blood sampling as an alternative blood collection method for DTC cancer patients, takes significantly less time and minimises the radiation exposure if employed post therapeutic administration of I-131. It may also possible for patients to perform the finger-prick blood collection themselves if a suitable tool were to be used.

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MONTE CARLO SIMULATION AND EXPERIMENTAL MEASUREMENTS OF OCCUPATIONAL EXPOSURE FOR IMPLEMENTING I-131 BLOOD AND BONE MARROW DOSIMETRY IN THYROID CANCER PATIENTS

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Purpose: Radioactive iodine (I-131) is administered for remnant ablation of differentiated thyroid cancer (DTC) post thyroidectomy. The European Association of Nuclear Medicine (EANM) has produced guidelines for tailoring personalised DTC treatment, requiring multiple whole body scans and blood withdrawals post administration of I-131 tracer capsules. In cases where pretherapy dosimetry does not represent the therapeutic body clearance, dosimetry can be performed during therapy for retrospective assessment of absorbed doses. While whole-body measurements can be acquired remotely, blood sampling requires that a health worker is in close proximity to the patient, leading to increased staff radiation exposures. To date, there have been very few studies reviewing radiation protection aspects, particularly blood sampling, while performing the EANM dosimetry protocol. Accordingly, this study aims to estimate staff exposures, using Monte Carlo modelling, as a result of blood sampling of DTC patients post therapeutic administration of I-131. The study further aimed to validate the models with staff exposure measurements and examine the impact of protective measures on the procedure, ensuring doses to staff do not exceed 0.3 mSv/year.
Material and methods: EGSnrc Monte Carlo simulations of blood sampling at 2, 6, 24, 48 and 120 hours post I-131 patient administration were performed, modelling the clinical set-up within the dedicated I-131 ablation therapy suite. Blood sampling scenarios with and without mobile lead screens were simulated, with patients and staff represented using a range of geometries including the ICRU 15-cm radius spherical phantom. Hp(10) and Hp(0.07) dose scoring was used to estimate deep and skin doses

to staff, with simulations corroborated with clinical monitoring of staff using electronic personal dosimeters (EPD).
Results: Preliminary Monte Carlo simulations estimated dose rates of 3.98 μSv/5min/patient and 194.8 μSv/5min/patient with and without the mobile screen present. Further refinements to the simulations will be presented, with the model capable of being tailored to clinical scenarios at any centre. The simulations will be corroborated with dosimetry data of blood sampling from 14 patients post administering 3.7 GBq I-131, amounting to a total of 54 measurements from 14 staff members. To date, cumulative deep dose rates have been measured as 5.7 μSv/5min/patient and 114.9±3.5 μSv/5min/patient with and without the mobile screen, respectively.
Conclusion: The accuracy of the Monte Carlo simulation approach for assessing radiation exposures to staff involved in new procedures, such as blood sampling post radioactive administration of patients, will be demonstrated.

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A LEAN SIX SIGMA APPROACH TO IMPROVING STAFF DOSIMETRY SERVICES
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Purpose: Beaumont Hospital (Dublin) is a large teaching hospital that provides a wide range of diagnostic and interventional radiological specialities to its patients, across various services. The Hospital's radiation safety and governance structures are committed to a safe working environment for staff working with ionising radiation. This is delivered through a range of radiation safety initiatives such as training and staff dosimetry programmes.
Staff working in areas with ionising radiation are required to wear radiation dosimeters to monitor their doses. A staff feedback session held in 2019 highlighted a lack of clarity in the staff dosimetry service. Based on these findings, a project was undertaken to improve the dosimetry programme within the Hospital.
Material and methods: A lean six sigma process improvement methodology was applied to review and improve the processes in place for monitoring staff doses. This method uses various tools to assess the quality of processes, including stakeholder analysis, process mapping and risks assessments.
The methodology was applied across 5 phases:
1. Define the problem.
2. Measure the baseline performance.
3. Analyse the process to establish the root cause of the issue.
4. Improve the process by implementing reliable solutions.
5. Control the improvements with documentation and metrics, ensuring that the changes are embedded.

Results: The main changes made to the staff dosimetry process are as follows:
- The method for requesting a dosimeter is now a semi-automated form, easily accessible to all staff via an online platform.
- This online platform provides a link to the radiation safety procedures and other radiation safety information, such as staff pregnancy guidance and how to obtain individual dose history.
- Radiation safety training completion is captured within the request record, to ensure compliance with the required radiation safety training.
- Quarterly compliance reports are published on the platform and communicated at Hospital governance and radiation safety meetings.

Conclusions: Using a Lean Six Sigma approach, the key issues were identified and tackled with effective and practical solutions. The transition to an online platform has enabled sharing of important radiation safety information easily with staff, and it has transformed the tracking and reporting capabilities within the department. Over the last two years, the new staff dosimetry programme has been embedded into routine use across the Hospital and there has been positive feedback from staff.

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ENVIRONMENTAL DOSIMETRY AS AN AID TO RADIATION RISK ASSESSMENT
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Purpose: The Imaging Group of the Medical Physics and Clinical Engineering Department at Beaumont Hospital(Dublin) perform routine environmental dosimetry within the Hospital's Radiology Department. This programme is performed to ensure adequate levels of radiation protection for staff and members of the public. This work informs the radiation risk assessment for both newly installed and existing X-ray rooms where imaging practices may have changed since the room was initially installed.
Methods and materials: Area monitoring is performed using dosimeters based on Optically Stimulated Luminescence(OSL) technology from an approved dosimetry service. Environmental dosimeters are placed around the X-ray room for a period of 3-9 months. The subsequent dosimetry results can then be used to infer the adequacy of the shielding present in the relevant boundaries.
Results: Environmental dosimetry results have been reviewed for a variety of different settings such as General X-ray Rooms(x2), Cardiac Cathlabs(x2) and Nuclear Medicine Waiting Area.
Case Study #1 General X-ray Rooms: An initial and repeated assessment at a wall behind the operator's console in both X-ray rooms showed measurements close to the design dose constraint of 0.3mSv per annum. These readings were as a result of changes in practice in these X-ray rooms. While staff working behind the lead glass screen were sufficiently protected at all times, it was decided to (i) place a demarcation line on the floor to remind staff to stand away from the opening at the end of the protective barrier and (ii) extend the protective barrier in one of the X-ray rooms.
Case Study #2 Cardiac Cathlabs: Dosimeter results have confirmed scattered radiation to be well within the required design dose constraint of 0.3mSv per annum, however the measured air kerma behind at one lead-lined door to the dirty utility approached the dose constraint. Scatter radiation levels were also recorded at several points on the C-arm itself as an indicator on maximum scatter.
Case Study #3 Nuclear Medicine Waiting Area: The annualised dosimetry readings from this area were observed and compared to those at initial installation. Scatter radiation levels were also measured in adjacent areas such as an adjoining patient changing cubicle and laminar flow cabinet.
Conclusions: Environmental dosimetry has proved a valuable tool to help inform the Hospital's radiation risk assessments. In addition, as expected, due to the conservative nature of the shielding calculations performed for these areas, the environmental dosimetry showed lower levels of scattered radiation in clinical practice.

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IMAGE QUALITY - DOSE OPTIMIZATION IN DBT: A PHANTOM BASED STUDY
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Purpose: Digital Breast Tomosynthesis (DBT) resolves dense tissue superposition, challenging Digital Mammography (DM). The combined use of DBT and DM improves lesion detection and diagnosis, at the expense of increased patient dose (and compression time rise). To this end, the synthetic 2-dimensional (s2D) image, generated from the DBT dataset, was introduced towards ultimately replacing DM.
The current study presents a phantom-based image quality inter-comparison among DBT, DM and (s2D) mammography, in terms of,Normalized Noise Power Spectrum (NNPS), Modulation Transfer function (MTF) and D' prime indices.
Material and methods: Radially averaged NNPS was estimated in a region of interest (ROI) of 50x50mm2 positioned in the center of the image, considering specific set up (2mm Al filter positioned as close as possible to x-ray tube) and varying exposure settings for DM (5,10,20,25,30,40,50 and 60mAs) and for DBT (18,21 and 25mAs).
MTF was estimated in equal sized ROIs positioned at each side of the Cu filter image (1 mm Cu filter positioned in 3o angle) considering varying exposure settings for DM mode (25 and 30mAs) and for DBT (21mAs). MTF and NNPS indices were calculated using IQ works software.
D' calculation model considered radius (R) of 0,05mm and 0,125mm and spatial frequency of 4,125mm-1 at varying exposure settings for DM (25 and 30 mAs).
Results: Analysis revealed that NNPS was isotropic in both directions(x-y) for DM and pre-processed (projection 0 degrees) DBT image. At reconstructed DBT slices, NNPS is approaching to zero at the perpendicular direction of tube movement (y-direction). For s2D mode, NNPS is maximized at low and medium spatial frequencies. Furthermore, MTF was higher for DM (MTF values 12,47) followed by s2D (6,44), pre-processed DBT(5,97), and reconstructed DBT (4,58). D' for DM demonstrated radius and exposure dependence (6,13 vs. 6,08 for R=0,05mm and 7,22 vs. 7,15 for R=0,125mm for 30 and 25mAs respectively).
Conclusions: The presented phantom-based image quality analysis suggested that the three mammographic modes (DBT, DM and s2D) are differentiated with respect to noise and MTF (spatial resolution) properties. Comparing the three modes in terms of d prime index is an immediate next step. Coupling image quality indices to specific dose estimates is crucial towards dose optimization across mammographic modes.

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COMPARISON OF COMMISSIONING MEASUREMENTS FOR A 6 MV FLATTENING FILTER FREE BEAM GENERATED BY UNMATCHED LINACS

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Purpose: To compare the commissioning measurements for a flattening filter free (FFF) beam generated by two unmatched linear accelerators using different dosimetry equipment.
Material and methods: Commissioning measurements for a 6 MV FFF beam generated by an Elekta Infinity linear accelerator were independently performed at two different sites. No attempt was made to match the machines. The first site used IBA detectors placed on a Blue phantom (IBA Dosimetry, Germany). Relative dosimetry on the second site was made using Sun Nuclear detectors and a 3D-Scanner water phantom (Sun Nuclear Corp, Melbourne,FL). The depth of the maximum dose (dmax) and the percentage depth dose measured at depths of 10 cm (PDD10) and 20 cm (PDD20) for 12 field sizes, as determined on the two linear accelerators, were compared. For eight field sizes, the discrepancy between the inplane beam profiles was found on the basis of the off-axis ratio (OAR) calculated at several points. The discrepancies between the crossplane profiles measured on the two machines were also determined. The total scatter factor (Scp) and the in-air output factor (Sc) for square and orthogonal treatment fields derived from the independent commissioning procedures were compared.
Results: The analysis of the PPD curves showed that the data measured with Sun Nuclear equipment were systematically higher than those derived from the IBA system. However, the absolute mean difference (MD) ± one standard deviation (SD) for the PDD10 and PDD20 was small and equal to 0.7±0.5% and 1.2±0.7%, respectively. The variability for the dmax was up to 1.3 mm. No systematic differences were found for the other parameters. The MD±SD for the OAR defined by the inplane and crossplane beam profiles was found to be 1.2±1.1% and 0.8±1.1%, respectively. The difference between the Scp values measured at two treatment sites was equal to 0.4±0.3% whereas that for Sc was 0.08±0.06%.
Conclusions: The FFF beam data derived from the unmatched linear accelerators for the process of commissioning were in a good agreement despite the use of different equipment.

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CUMULATIVE RADIATION DOSES IN LYMPHOMA PATIENTS FROM DIAGNOSTIC PROCEDURES: PRELIMINARY RESULTS

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Purpose: In the last years, the cumulated doses received by patients undergoing recurrent high dose radiological imaging procedures has become a subject of international concern, leading to a call for action aimed at strengthening the radiation protection of these patients.
Material and methods: Twenty-six patients with Hodgkin's lymphoma (HL, 11F-15M, median age 49y, range 21-81y) and forty-one patients with diffuse large B-cell lymphoma (DLBCL, 21F-17M, mean age 69y, range 35-90y) were retrospectively evaluated in terms of cumulated effective dose (CED) received by the radiological imaging procedures (CT and PET/CT) received in the follow up period. The effective dose from the CT examinations was evaluated by means of the dose monitoring system GrayDetector (EL.CO srl, Italy) based on the Virtual DoseTM CT software (Virtual Phantoms Inc., NY) that uses the acquisition parameters of each scan received by the patient, anatomically correct phantoms and Monte Carlo simulations. The effective dose from PET imaging was evaluated from the individually administered 18F-FDG activity extracted by the radiologic information system Fenix (EL.CO. srl, Italy) and the correspondent dose-activity conversion coefficients. The CED was evaluated for diagnostic CT and PET/CT examinations for LH and DLBCL patients.
Results: The median follow-up period of LH patients was 2.6 y (range 1.1-3.9y). They had a median number of 4 diagnostic CT (range 0-8) and 3 PET/CT (range 1-7) examinations, that contributed with a median CED of 100 mSv (0-268 mSv) and 31 mSv (10-65 mSv), respectively. The median total CED was 127 mSv (21-311 mSv). The percentage of patients with total CED > 100 mSv was 73.1%.
The median follow-up period of DLBCL patients was 2.9 y (range 1.5-4.0y). They had a median number of 4 diagnostic CT (range

1-10) and 2 PET/CT (range 0-6) examinations, that contributed with a median CED of 119 mSv (10-252 mSv) and 20 mSv (0-64 mSv), respectively. The median total CED was 140 mSv (22-282 mSv). The percentage patients with total CED > 100 mSv was 65.9%.
Conclusions: Data collected in this study indicates that about two thirds of the patients with HL and DLBCL undergoing CT or PET/CT exams received radiation dose from multiple imaging with CED≥ 100 mSv during a follow-up period of about 3y. While underscoring in general the need for imaging appropriateness, these results raise a concern for LH patients, who are relatively young (50% of them fall within the age group≤50 years) and with a long life expectancy.

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MINISCIDOM: A SCINTILLATOR-BASED TOMOGRAPH FOR RECONSTRUCTION OF MM-SCALE DOSE DISTRIBUTIONS
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Preclinical in-vivo studies in radiation therapy face many challenges: chief among them the efficient characterization of radiation fields and consequently accurate reference dosimetry, especially for small volumes (~). Radiobiological protocols require delivery of variable prescribed homogeneous volumetric dose distributions within percent-level margins achievable only trough beam monitoring and radiation field optimization.
Established methods, e.g. radiochromic films, can serve as reference dosimeters, however offline evaluation prevents immediate feedback to the experiment. This is the case for radiobiological studies performed at Helmholtz-Zentrum Dresden Rossendorf with protons produced by DRACO laser system and transported by the pulsed ALBUS-2S proton beamline.
We present the miniSCIDOM detector: a compact tomograph for online reconstruction of mm-sized 3D dose distributions. Detection is based on emission tomography: 4 parallel projections of a 3D light distribution, generated in a hexagonal-shaped plastic scintillator, are imaged by a bi-telecentric objective and a CCD camera.
Reconstruction of the 3D light distribution is performed by an iterative algorithm based on maximum likelihood expectation maximization. LET dependent quenching of the scintillator light out-put is corrected, for the measured dose distributions, via Birks' law and simulated fluence weighted LET values.
We tested detector performance with bremsstrahlung photons (30-230 KeV), cyclotron protons (90-150 MeV), and Laser Plasma Accelerated (LPA) protons (~ 30 MeV), provided by clinical and research accelerators.
Using an X-Ray source (low LET, low dose rate ~Gy/min), we achieve 3D reconstruction in the absence of scintillator quenching or saturation.
Using a cyclotron proton beam (high LET, low dose rate ~Gy/min), we understand and correct LET-dependent quenching both for monoenergetic and polyenergetic beams.
Lastly, measurements at ALBUS-2S proton beam-line, (high LET, high dose rate) are performed to study dose-rate dependence and quenching effects.
The miniSCIDOM device allows online tomographic reconstruction of mm-sized 3D dose distributions. The lower detection limit lies below 500 mGy and the upper dose limit can be modified using filters, currently tested up to a 20 Gy level. The light reconstruction reaches a resolution 400 µm (comparable with depth resolution of RCF).
For protons with conventional (~Gy/min) dose rates the expected scintillators' quenching behavior described by Birks' law is observed. For the ultra high dose rates at the ALBUS-2S proton beam-line (10^8 Gy/s in ~ns proton pulse), deviation from Birks' law is detected, opening the question of the reduction of the quenching behavior of scintillators for dose application in the time scale of the scintillator time response function.

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DEVELOPMENT OF LEAD FREE MULTILAYER COMPOSITES FOR RADIATION SHIELDING
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Purpose: To create and analyse the multilayer composites for radiation shielding.
Materials and methods: Multilayer lead free composites of different molality concentration have been developed. Composites were produced using two parts (A and B) of thermally curable vinyl terminated polydimethylsiloxane (PDMS) silicone rubber Endeavour T-1006 (Endeavour Enterprise Co, Taiwan) with embedded tin, cerium oxide, tungsten oxide and bismuth powders.
X-ray attenuation properties of multilayer composites were investigated following internationally accepted guidelines. Investigation of X-ray attenuation was performed placing experimental samples in direct irradiation field (100 x 100 mm) of X-ray machine AXIOM ICONOS R200 (Siemens Medical) and measuring radiation doses with "Piranha" multimeter (RTI electronics, Sweden). Measurements were performed at different X-ray tube voltages (40, 60, 81, 100, 121 and 141 kV) keeping the distance of 100 cm between X-ray tube focal spot and the multimeter detector.
Mechanical properties were investigated following ISO 6721 standard and using the ElectroPuls E10000 Linear-Torsion (Instron, USA) machine. Static and cyclic tensile examinations of experimental samples have been performed.
Results: Analysis of the multilayer composites revealed that the alteration of the molality of different additives in composite layers allows for variations of X-ray attenuation properties. Also the impact of additives molality on composite's mechanical properties was assessed.
Conclusions: Newly fabricated multilayer composite containing separate silicone rubber layers with embedded tin, cerium oxide, tungsten oxide and bismuth powders, indicated 0.25mmPb radiation shielding ability, however was more flexible and less heavy as compared with the material of lead aprons that are still used for radiation protection of personnel.

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COMPARISON OF RADIATION DOSE AND IMAGE QUALITY FROM SINGLE-ENERGY AND DUAL-ENERGY CT EXAMINATIONS FOR OPTIMIZATION OF RENAL CALCULI IDENTIFICATION
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Materials and methods: In this study image quality using catphan 600 phantom of Single Energy CT (SECT) versus Dual Energy CT (DECT) in a Revolution Evo CT GE was studied and analyzed with AutoQA Plus software. Subsequently dosimetric data from dose registration software Virtual Dose was extrapolated to calculate the effective dose in a cohort of 10 patients that underwent SECT examinations and 10 patients with DECT examinations respectively.

Results: Noise and uniformity level measured in standard SECT acquisitions were 7 and 1.8 HU while for DECT GSI acquisition were 8.3 and 1.1 HU respectively. Both noise level and uniformity are comparable in both acquisition modes.
Instead the effective dose calculated in SECT was 18.2 +/- 5.4 mSv while that in DECT acquisition was 13.2 +/- 2.5 mSv. The difference is statistically relevant (p=0.04) despite the small number of patients analyzed.
Conclusion: DECT imaging of the renal calculi can achieve noise levels comparable to those seen with SECT imaging with considerable dose reduction.

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CARDIAC CATHETERISATION LAB – HIGH RADIATION PATIENT DOSE MONITORING

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Purpose: Patient radiation doses in interventional cardiology procedures can accumulate rapidly due to prolonged fluoroscopy screening and return visits within a short period of time (i.e. less than 1 year). In line with Irish legislation (originating from BSS)[1] there is an imperative on all health providers using ionising radiation to record, provide and optimise radiation dose to patients.
Methods and materials: In our hospital, GE DoseWatch is installed on the Cath Labs. DoseWatch is useful in setting dose alert levels, cumulative dose incidence maps, skin dose maps and it also generates a Reference Point Air Kerma (RPAK) value. Using the Society of Interventional Radiology (SIR)2 guidelines, the RPAK value can be converted to estimate the Peak Skin Dose (PSD) value using a formula. Estimating the PSD can help in predicting deterministic radiation injuries to the patient.
Patient skin doses in some interventional procedures can reach those received in some cancer radiotherapy fractions. These procedures can result in erythema, permeant epilation, skin necrosis etc.
Results: ICRP Publication 85 states "Many patients are not being counselled on the radiation risks, nor followed up when radiation doses from difficult procedures may lead to injury." This study will demonstrate the setup of a high radiation patient dose monitoring program which is multi-disciplinary approach between Radiology and Cardiology departments.
This program tracks:
- the high dose procedures in the Cath Lab;
- cumulative patient doses; and
- set up a method to flag any return patients with a high cumulative dose.

We will also look at presenting information to the patient regarding their high dose, and also presenting this information to the patient's referring clinicians.
This program will be a holistic review of the patients journey through the Cath Lab in conjunction with reports such as the ICRP Publication 853 and SIR Guidelines 20092.
References:
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[2] Stecker MS, Balter S, Towbin RB et al.: Guidelines for patient radiation dose management. J. Vasc. Interv. Radiol. 20, 263–273 (2009).& Guidelines for patient radiation-dose management developed by the Society of Interventional Radiology Safety and Health Committee.
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EVALUATION OF THE RADIATION PROTECTION PROVIDED BY FIRE STOPPING MORTAR IN A NEW DIAGNOSTIC IMAGING FACILITY

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Purpose: This work investigates and evaluates the radiation protection provided by a fire stopping mortar (Firecrete) which will be used to fill openings and gaps in the floors and ceilings of different areas throughout the new hospital of Children's Health Ireland (CHI).
Material: Core samples of the Firecrete mortar, from the site of the new hospital, were provided to evaluate its attenuation properties and to determine if the material can provide adequate protection in the floors and ceilings of interest.
Different code lead samples were also provided to compare its attenuating properties with the Firecrete mortar.
Methods: The Firecrete core and lead samples were evaluated using 2 different methodologies as outlined by the BIR radiation shielding publication (2012).
1. γ-ray source method: Assessed the attenuation of a radioactive source, Tc-99m, through the different codes of lead and Firecrete core sample thicknesses Attenuation was measured using a scintillation meter at a set distance.
2. X-ray source method: Assessed the attenuation of X-rays through the sample materials. The radiation output was measured using a solid state meter over a range of kVp values.
Results: The results from the X-ray source method and Archer equations indicate that the lead equivalence of the Firecrete increased with kVp, from 70 – 100 kVp, plateauing at 125 kVp. At the typical thickness used in the building, 200-300mm, the lead equivalence was found to be 1.5-3mm.
The results also show a discrepancy between the two different methodologies, as the results from the γ-ray source method appear to have underestimated the lead equivalence of the Firecrete material. This needs to be considered when using this methodology in situ.
Conclusion: The γ-ray source method is excellent at evaluating the shielding for lead based materials and is easy to employ for in situ measurements. However it may not be the most appropriate method for other shielding materials.
The X-ray method can be used to accurately evaluate the shielding properties of other materials (Concrete or Gypsum) or barriers where the composition is not known but is not always practical to follow in building site conditions.
The Firecrete mortar evaluated in this work was shown to meet the required radiation shielding for the floors and ceilings of the different imaging rooms of the new Children's hospital.

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EVALUATION OF FLUOROSCOPY TYPICAL DOSES DUE TO FLUOROSCOPY VERIFICATION OF THE POSITION OF CYLINDRICAL APPLICATORS DURING THE SECOND AND THE NEXT GYNAECOLOGICAL BRACHYTHERAPY FRACTIONS

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Purpose: Article 56(1) of the Directive 2013/59/2013 state that all doses due to medical exposure including planning, guiding and

verification purposes are kept as low as reasonably achievable. During the gynaecological brachytherapy treatment with cylindrical applicators, the position of the applicators are checked directly on the operative room with the c-arms. The purpose of the study was to assess the level of the doses and to set local reference levels for this type of the procedures.
Methods: All the DAP data from 2020 (80 procedures) has been collected, which allow us, according to ICRP 135, to omit BMI of the patient due to enough large cohort. Dose data are analysed in the excel file. Results has been compared with the preliminary dose data survey with 12 patients from 2019.
Results: Statistical analysis of the DAP (cGy*cm^2) in 2020 results: mean 12,27; standard deviation 11,57; median 9,26; 25th percentile: 4,88; 75 percentile 15,51; min 1,34 vs +19,25%; max 73,93. The change of the values compared to the preliminary set up values based on the first research in 2019: +19,25% (mean); (+30,54%) median; +7,56% (75th percentile). Both mean and median in 2020 do not exceed 14,42 cGy*cm^2 75th percentile established in 2019.
Conclusion: Collecting the typical doses and setting the reference levels for the c-arms, which are used for the verification purposes during brachytherapy, is feasible and can be performed with similar methodology to other interventional procedures. LDRL is found to be 15,51 cGy*cm^2. The level of the doses associated with the imaging are far below the therapeutic ones, nevertheless tracking radiological doses due to guiding or verification of the brachytherapy is important from legal and from ALARA point of view.

EPOSTER ABSTRACTS – RT

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EVALUATION OF IONIZATION CHAMBER STABILITY BY DIFFERENT RADIOACTIVE CHECK SOURCE DEVICES

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Purpose/objective: Radioactive check devices are commonly used for evaluation of ionization chamber stability in radiotherapy, between two consecutive calibrations. The purpose of this work was to evaluate performances of farmer type ionization chambers in different check sources.
Material and methods: Two farmer type chambers, manufactured 12 years ago and regularly calibrated biannually, were tested in three different check sources. Radioactive check devices contained 90Sr (T1/2=28,7 years) at the bottom of each device with initial activity around 30MBq. To compare between devices, one should apply temperature and pressure correction as well as decay factor. The chambers were fixed by the holders delivered with the devices by manufacturers. The tests performed were recommended by IEC 60731 and included: leakage current, short-term reproducibility, linearity with time, chamber orientation dependence. The same test on chamber orientation dependence was performed in a 6MV beam of linear accelerator Varian iX series in three different ways. One in the solid water phantom in which the chamber axis was perpendicular to the beam axis. Also with build up cap in the air with two different types of chamber axis orientations: ionization chamber axis perpendicular to the beam axis as it is recommended in IEC standard and chamber axis parallel to the beam axis in order to have geometry that is similar to the position of chamber in check source. Chamber orientation dependence was examined for four different angles separated by 90.
Results: Both chambers were performing far better than required by IEC: the difference between all measurements was better than 0.5%. The only result that brought attention was angular dependence. The measurement performed in the accelerator beam showed that there is practically no angular dependence of the ionization chamber, regardless of chamber axis orientation or type of phantom used. In radioactive check source devices, results are showing some angular dependency that seems to be different for different devices and do not depend on the chamber. In source I it is always below 0.5%, source II shows dependence below 1%, while in check source III it is much higher.
Conclusion: The performance of ionization chambers depends on the chamber itself, but still non-uniformity of the source placed at the bottom can have a high influence on the result. One should be aware that the devices are performing depending on the source homogeneity installed inside. For more accurate results angular dependence should be evaluated in the accelerator beam as well.

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THE POTENTIAL OF CYBERKNIFE TO DELIVER SBRT USING DYNAMIC ARCS

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Purpose: The Cyberknife® M6™ System is a well-established device for delivering stereotactic body radiotherapy (SBRT), but treatment times are long, mainly due to the time for repositioning the robot between beams and for repositioning the leaves of the multileaf collimator (MLC) between segments. This study therefore uses planning simulations to investigate the expected plan quality, treatment time and dosimetric accuracy of delivering SBRT treatments using dynamic arcs.
Material and methods: Five planning target volumes (PTVs) were retrospectively studied: conventional prostate, brachytherapy-like prostate, central lung, liver and partial breast. Plans used a standard 110-beam body robot path with step and shoot (S&S) segments and also a 104-segment dynamic arc path with segment spacing of 5°, designed to cover the collision-free space around the patient. Dose was calculated using interpolated apertures to accurately model the movement of the MLC leaves between control points. Delivery times were estimated for the S&S plans by allowing for robot movement, MLC movement, and time for dose delivery. For the arc plans, the MLC motion and dose delivery occurred during the robot movement. Accuracy was assessed by applying probability distributions of uncertainty to the dose rate, MLC leaf position and robot orientation of the resulting plans.
Results: Numbers of monitor units, conformity indices and dose-volume statistics are similar for both dynamic arc and S&S delivery. Using dynamic arcs, dose to critical structures is higher by up to 5% of the prescribed dose, due to the fewer segments in the plan. Median estimated delivery time is 675s for S&S delivery and 355s for dynamic arcs, excluding treatment set-up. A 5% random variation in dose rate over a 30s time period causes a 1% variation in monitor units, affecting the PTV mean dose accordingly. A lag in MLC leaf position of 0.5mm changes mean PTV dose by around 1%, and a random variation in robot target position of 1mm increases PTV dose heterogeneity by around 2% of the prescribed dose, while changing mean PTV dose by up to 1%.

Conclusions: Delivering SBRT with multiple non-coplanar dynamic arcs on Cyberknife is expected to give similar plan quality to the current method of non-coplanar S&S delivery but a delivery time of around half that of S&S delivery. The additional dosimetric uncertainty associated with dynamic delivery is estimated to be better than 1-2%. We are grateful to Accuray Inc. for funding this work.

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A PHASE SPACE MODEL OF A VERSA HD LINEAR ACCELERATOR FOR APPLICATION TO MONTE CARLO DOSE CALCULATION IN A REAL-TIME ADAPTIVE WORKFLOW

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Purpose: Recent developments in intrafraction imaging offer scope for treatment plans to be updated and recalculated in real time so as to follow the observed anatomical changes. This study therefore aims to develop and validate a simple geometric model of the accelerator head, from which a particle phase space can be calculated for application to fast Monte Carlo dose calculation. The particular objective of this study is to investigate whether the phase space model can facilitate dose calculations which are compatible with those of a commercial treatment planning system, for convenient interoperability.
Material and methods: A dual-source model of the head of a Versa HD accelerator (Elekta AB, Stockholm, Sweden) was created. The model consisted of rays traced through the collimators and multileaf collimator to produce a grid of divergent photons. For each discrete source, the array of photons was convolved with a Gaussian function to model the finite size of the source. The model used parameters chosen to be compatible with those of 6-MV flattened and 6-MV flattening filter-free beams in the RayStation treatment planning system (RaySearch Laboratories, Stockholm, Sweden). The phase space model was used to calculate a photon phase space for several treatment plans and the resulting phase space was applied to the Dose Planning Method (DPM) Monte Carlo dose calculation algorithm. Simple fields and intensity-modulated radiation therapy (IMRT) treatment plans for prostate and lung were calculated for benchmarking purposes and compared with the convolution-superposition dose calculation within RayStation.
Results: For simple square fields in a water phantom, the calculated dose distribution agrees to within ±2% with that from the commercial treatment planning system, except in the buildup region, where the DPM code does not model the electron contamination. For IMRT plans of prostate and lung, agreements of ±2% and ±6% respectively are found, with slightly larger differences in the high dose gradients. For the IMRT plans, calculation time is of the order of 3 minutes on a 4-core processor using 8 threads.
Conclusions: The phase space model presented allows convenient calculation of a phase space for application to Monte Carlo dose calculation, with straightforward translation of beam parameters from the RayStation beam model. This provides a basis on which to develop dose calculation in a real-time adaptive setting. Real-time operation may be feasible by scaling up to a multi-processor environment and applying more sophisticated statistical noise reduction. Supported by Cancer Research UK ART-NET (A21993).

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VALIDATION OF A TRANSIT DOSIMETRY SOFTWARE WITH IONIZATION CHAMBER MEASUREMENTS

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Purpose: Transit dosimetry in external beam radiotherapy treatments is based on image acquisition through the patient during field irradiation with the electronic portal imaging device (EPID). PerFRACTION (Sun Nuclear Corporation) is a software for in-vivo transit dosimetry that converts the transit image to an absorbed dose distribution in the middle plane of a 50×50×4.9 cm^3 water phantom. Such dose distribution can be compared with the expected dose distribution calculated by the software.
This work aims to validate the PerFRACTION algorithm for expected transit dose values with dose values determined with ionization chamber measurements under transit dosimetry conditions.
Material and methods: Forty-three treatment fields were studied, both static and dynamic. The static fields were: the nine asymmetric fields needed to calibrate PerFRACTION, three jaws-defined (20x20, 6x6 and 10x10 cm^2) and two MLC-defined fields (2x2 and 3x3 cm^2). The dynamic fields were 29 IMRT fields from 10 breast treatment plans. All fields were delivered through three different thickness solid water phantoms: 10 cm, 30 cm and a 3 cm cork slab placed between 10 cm of solid water. Hence, a total of 129 fields were analysed.
The transit dosimetry images were acquired with the EPID placed at 150 cm from the source. From every image, a representative dose value from a homogeneous region was obtained from PerFRACTION expected dose distribution.
To perform the ionization chamber measurements, a solid water phantom of 30x30 cm^2 and 5.5 cm-thick was placed on the EPID cover. The measurement point was at 150 cm distance from the source and at a depth of 2.5 cm. The phantom was moved laterally, if necessary, to reproduce the PerFRACTION representative points. IMRT and static MLC-defined fields were measured with a PTW PinPoint3D ionization chamber, while the rest with a PTW Farmer chamber.
Results: Comparison of PerFRACTION expected dose values with measured dose values, shows mean differences of 0.4±1.1% for IMRT fields (range = [-3.1%, 2.9%] and |95th percentile| = 2.3%) and 0.1%±1.2% for static fields (range = [-1.8%, 2.9%] and |95th percentile| = 2.1%).
The mean difference between different thickness phantoms varies as maximum of 0.5% for IMRT fields and -0.4% for static fields.
Conclusions: We validated the PerFRACTION algorithm for expected dose values with experimental measurements under transit dosimetry conditions for static and dynamic fields, and homogenous and heterogeneous phantoms.

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A FEDERATED LEARNING IT-INFRASTRUCTURE TO SUPPORT THE DUTCH MODEL-BASED APPROACH FOR PROTON THERAPY

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Purpose: In the Netherlands, patients are selected for proton therapy (PT) using the model-based approach, based on normal tissue complication probability (NTCP) models to translate dose differences in OARs (Δdose) into differences in NTCP (ΔNTCP). Currently, these NTCP-models are based on patients treated with modern photon techniques with the assumption that these models perform similarly among patients treated with protons. In order to collect multi-center data to validate these NTCP-models with data from patients treated with proton therapy, a national IT-infrastructure was developed to (ProTRAIT, protrait.nl). The installation of this IT-infrastructure has recently been completed and is therefore ready for development and validation of these NTCP models. Our main objective was to test this national IT-infrastructure, by performing a proof-of-concept external validation of an NTCP-model predicting grade 3+ dysphagia at six months after treatment.
Materials and methods: We used a dataset of 320 head and neck (HNC) patients that were treated between 2019-2021 with (chemo)radiotherapy in MAASTRO clinic. Using semantic web technologies, the data variables needed for the computation of the NTCP model formula as presented in figure 1 in the Google document (https://docs.google.com/document/d/1MPaiNkEyAGN_GiQr1qlT_oT3chuIBJ4DnKAU2ElBz-Y/edit) were transformed in a machine-readable and Findable Accessible Interoperable (FAIR) data principles[1] for the implementation of the PHT. Following the closed testing procedure methodology[2] the statistical algorithm for the federated NTCP external validation was built in the RStudio software and constitutes the statistical "train" that will be exchanged among the different proton therapy centers (figure 2 in the Google document https://docs.google.com/document/d/1MPaiNkEyAGN_GiQr1qlT_oT3chuIBJ4DnKAU2ElBz-Y/edit).
Results: After the "FAIRification" of the patient data, we successfully implemented the statistical analysis-"train" needed for the external validation in our dataset. The performance of the original NTCP model for grade 3+ dysphagia (which was adopted as the updated model from the closed testing procedure[2]) had reasonable discriminative power in the MAASTRO's cohort (AUC=0.84). Furthermore, we established the end-to-end IT-infrastructure needed in our center according to the requirements of the federated learning ProTRAIT IT-infrastructure.
Conclusion: This study validated the existing which grade 3+ dysphagia NTCP model for the first time using the Personal Health Train infrastructure (PHT)[3]. Future work will focus on extending more applications of the different components of the model-based approach such as the model-based clinical evaluation, including NTCP-model development and validation without the exchange of patients data in a federated fashion with data from the other proton therapy centers.
References:
[1] PubMed ID: 26978244
[2] PubMed ID: 27891652
[3] https://pht.health-ri.nl/

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A MONTE CARLO STUDY OF THE FREE RADICAL PRODUCTION IN MINIBEAM RADIATION THERAPY

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Purpose: Minibeam radiation therapy is a novel treatment technique characterised by the use of narrow beamlets to create spatially fractionated distributions of high (peak) and low (valley) doses. This technique has been shown to widen the therapeutic window, and takes advantage of the dose-volume effect, leading to an enhanced normal tissue tolerance to radiation. Comparatively, the biological principles underpinning this new technique are not as well understood as the physics. Consequently, we undertook an investigation into the production of free radical species during water radiolysis in an attempt to bridge this gap in knowledge. Our goal was to assess whether the composition of reactive oxygen species (ROS) differed between the peak and valley regions.
Material and methods: All simulations were performed using TOPAS-nBio, a Monte Carlo code which is based on and extends Geant4-DNA. A water phantom was irradiated with protons of 100 MeV and 69 keV effective energy x-rays in both broad beam (BB) and minibeam (MB) configurations. The primary yield at 1000 ps of the hydroxyl radical (the primary indicator of indirect DNA damage) was calculated in spherical cellular targets, located at various depths on-axis (peak) and at some lateral distance off-axis (valley).
Results: While we observed no inherent difference between the types of ROS produced in the peak and valley regions, the absolute yield of each species was dependent on the spatial distribution of each radiation type. At all depths, the hydroxyl yield for x-rays was approximately 1.6 times larger in the MB peak and 18 times smaller in the valley compared to the BB configuration. For protons these ratios in the entrance region were 5.6 and 60 respectively, but approached unity towards the Bragg peak region.
Conclusions: In a target located at the Bragg peak, the peak-to-valley ROS ratios suggest a differential indirect DNA damage effect for x-rays, whereas for protons this damage can be expected to be more homogenous. At the end of the non-homogenous chemical stage of water radiolysis, the distribution of free radicals appears to be analogous to the macroscopic absorbed dose. Further simulations are currently being performed to calculate the direct and indirect DNA strand breaks, and investigate the effect of diffusion between peaks and valleys of these ROS at larger time scales.

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A RECURRENT NEURAL NETWORK FOR IDENTIFYING DELIVERY ERRORS DURING REAL-TIME PORTAL DOSIMETRY

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Purpose: The forward-projection method of real-time portal dosimetry compares measured images with predicted images to identify delivery errors before the radiotherapy treatment proceeds too far. Historically, the process of error detection has used signal thresholds to signify an error occurring. This work aims to investigate a different approach, in which a recurrent neural network is used for processing image metrics, so as to identify delivery errors as early as possible in the treatment.
Material and methods: Volumetric modulated arc therapy plans of six prostate patients were used, each plan consisting of 180 segments for a 6-MV Versa HD accelerator. Sequences of predicted portal images were generated based on a water-equivalent phantom. Deliberate errors were then introduced, consisting of an increase in monitor units of 2-10%, an opening of the multileaf collimator by 2-10 mm, a shift of the multileaf collimator of 2-10 mm, and introduction of an air gap of 10-50 mm into the phantom, and sequences of portal images were acquired using an iViewGT portal imager. Detection metrics were central axis signal, mean image value and two root-mean-square difference measures. A threshold-

based method was used to identify the errors as soon as possible during the delivery, and a recurrent neural network consisting of four layers was also applied to the metrics. The neural network was trained using a non-convex objective function with variable penalty dependent upon the magnitude of the error being detected and the timeliness of detection. The study was designed to ensure that neither the threshold method nor the neural network produced false positives. A leave-two-out approach was used to set thresholds and train the neural network then test the resulting systems.

Results: When using a combination of metrics in conjunction with thresholds, the median segment index at which the errors are identified is 107 (range 72-117). When using the neural network, the mean segment index for error identification is 67 (range 51-84). Both the threshold method and the neural network are efficient at detecting errors in multileaf collimator opening, but the neural network is particularly beneficial for detecting errors in monitor units and path length. No false positive results are observed.

Conclusions: The recurrent neural network allows the identification of errors around 30% earlier than when using conventional threshold techniques. By appropriate training of the network, false positive alerts can be prevented, thereby avoiding unnecessary disruption to the patient workflow.

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PERFORMANCE EVALUATION OF KNOWLEDGE-BASED MODEL FOR LEFT BREAST AND LYMPH NODES RADIOTHERAPY TREATMENT PLANNING

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Purpose: The purpose of this study was to evaluate the performance of a knowledge-based model for volumetric modulated arc therapy (VMAT) treatment planning for left breast and lymph nodes.

Material and methods: This study applied a knowledge-based planning model using commercial RapidPlan (Varian Medical Systems, Palo Alto, CA) for left breast or chest wall and lymph nodes. The model was generated by using 35 previously treated VMAT treatment plans (ad 40.05 Gy in 15 fractions). Both deep-inspiration breath-hold and free breathing patients were included in the model. The performance of the model was analysed with 10 test patients that were not included in model training. The model was applied to generate VMAT treatment plans for these 10 test patients using single optimisation. Performance evaluation was conducted by comparing the knowledge-based generated treatment plan parameters of planning target volume (PTV) and organs at risk (OAR) structures to manually optimised treatment plans. The OAR parameters were evaluated based on the QUANTEC and RTOG guielines. The study analysed also the difference in monitor units (MUs).

Results: The average differences between PTV parameters were 0.0±0.8 percentage points and 0.4±0.5 percentage points for D95% and D5%, respectively. The model reduced the average dose by 0.1±0.7 Gy, 1.2±0.8 Gy, 0.8±1.0 Gy, 2.1±2.2 Gy and 2.9±2.0 Gy for heart, contralateral lung, contralateral breast, left humeral head and trachea, respectively. For ipsilateral lung, the mean dose and V17Gy were reduced by 0.9±1.7 Gy and 1.7±4.7 percentage points by using the model, respectively. The MUs in the knowledge-based generated treatment plans were higher on average by 6.8% with the maximum difference of 17.5% than in manually optimised treatment plans. From the 10 knowledge-based generated treatment plans, 9 were clinically acceptable. The unaccepted plan was due to lack of delineated OAR structures below ipsilateral lung segment.

Conclusion: This study supports application of knowledge-based treatment planning for left breast and lymph nodes. Nearly all of the treatment plans generated with the applied RapidPlan model were clinically acceptable, and in most cases the OAR sparing was improved compared to that in manually constructed plans. Although the automated planning reduces workload, the user input is still mandatory for plan verification. The research continues by further improving the model with high quality treatment plans to achieve even higher plan consistency. The following studies apply testing of the knowledge-based planning for high amount and variety of cases.

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REDUCTION OF MEAN HEART DOSE IN WHOLE LUNG IRRADIATION WITH VMAT TECHNIQUE FOR PEDIATRIC PATIENTS

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Purpose: Whole lung irradiation is commonly used in the management of metastatic stages of Wilms tumor and Ewing sarcoma in pediatric patients. The heart is the main organ at risk of this treatment site. Traditionally these treatments were based on a 3DCRT AP/PA technique. Recent publications show that VMAT improves the heart sparing with respect to 3DCRT technique. However, there is a lack of published data on relevant heart dose parameters using VMAT. We studied the PTV coverage and heart sparing for a set of VMAT plans for whole lung irradiation in pediatric patients. Our results were compared with recent literature [1-3].

Methods and materials: This retrospective study analyzed VMAT plans from 8 pediatric patients treated with whole lung irradiation. Median age of the patients was 6 yo (range: 2-16 yo). The prescription dose was 12 Gy in 8 fractions (3 patients) or 15 Gy in 10 fractions (5 patients). In all cases the simulation CT was acquired in free-breathing mode and the PTV was defined as the whole lung plus an isotropic margin of 5 mm. All plans were delivered using 6 MV photon beams from a Varian TrueBeam linac using VMAT technique with 2-3 coplanar full arcs. Dose distributions were calculated using the AcurosXB algorithm from the Varian Eclipse treatment planning system v. 15.6.04.

PTV coverage parameters (V95% and V90%) and mean heart dose were extracted from the dose-volume histograms. Mean heart dose was expressed as a percentage of the prescribed dose in each case to consider the different prescription dose levels. Results were compared with published data.

Results: For the PTV coverage, we obtained V95% = 92.5%±1.9% and V90% = 97.4%±1.2%, which are slightly lower than published data: 96.5% [1], 95.8% [2], 98.3% [3] for V95%, and 98.4% [1], 99.2% [2], 99.1% [3] for V90%.

The mean heart dose was of 45.8%±5.6% of the prescription dose, which is also lower than published data: 56.6% [1] (case report), 70.8% [2] (case report) and 72.5%±9.1% [3] (11 cases).

Conclusions: The VMAT technique for whole lung irradiation of pediatric patients allowed reducing the mean heart dose below 50% of the prescribed dose, without compromising the PTV coverage.

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VARIATION OF THE 6 MV PHOTON OUTPUT OF A LINEAR ACCELERATOR OBTAINED WITH TWO DAILY CHECKING SYSTEMS

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Purpose: This study aims to compare two different systems used for the daily monitoring of the accelerator output variation during the first three months of operation in order to decide which method is more reliable.

Material and methods: The output variation of the Truebeam (Varian) linear accelerator is checked daily, among other tests. To analyse the daily variation of the output we used two systems: 1) the tool available for this purpose in the Machine Perfomance Check (MPC) software installed in the Truebeam based on the average percentage reading collected in the central part of the amorphous silicon detector Electronic Portal Imager Device (EPID) of the Truebeam itself, 2) the reading of the central ionization chamber of the QUICKCHECK daily measurement equipment (PTW) based on ionization chambers. The tolerance established for both methods is ±2% with respect to the reference and the parameter of analysis is the percentage variation with respect to the reference.

Results: The average of the daily relative variation of the output for the 6 MV photon energy obtained with the QUICKCHECK was (0.6±0.31)%, while with the MPC tool through the EPID it was (-0.15±0.37)%. The MPC values obtained with EPID are always bellow those obtained with QUICKCHECK, and in quite a few occasions the direction of the variation is opposite to that shown by QUICKCHECK. Although the temporal evolution of the values is similar (with a significant scale difference between the two systems), if we analyze the values individually we observe that the EPID shows a random behavior.

Conclusions: The random behavior of the EPID makes us prefer the QUICKCHECK for daily monitoring of the accelerator output. Moreover, the QUICKCHECK values are consistent with those obtained with the Farmer camera in our monthly dose monitoring. However, regardless of the EPID, the MPC tool help us to anticipate or prevent changes in the EPID response through the trend of its response as it is used to perform other types of very valid tests.

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A DOSIMETRIC COMPARISON OF SOURCE PATH RECONSTRUCTION METHODS IN RING AND TANDEM APPLICATORS FOR GYNAECOLOGICAL BRACHYTHERAPY

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Purpose: Ring and tandem gynaecological applicators have long been used in brachytherapy for the treatment of cervical cancer. A key step in the use of these applicators is the reconstruction of the source path as it traverses the lumen of the ring and tandem.

Applicator reconstruction is currently performed manually in our hospital, where we define the source path based on the location of CT-visible marker wires. This results in a source path that can be subjective, both because of the position of the marker wire, and the user reconstructing it. An alternative to manual reconstruction is available in the form of a manufacturer supplied applicator modelling library. Applicator model library plans can be considered to be the gold standard for source path reconstruction, providing the most accurate prediction of where the source will be positioned at any point along the lumen.

Methods: This study retrospectively compared the dosimetry from 15 previously treated cases, which were manually reconstructed, with the equivalent plans generated using the appropriate applicator library models. The comparison plans utilised image data from previous treatments, along with physician-approved OAR structures, identical dwell positions, and identical dwell times to deliver the same prescribed dose as the original treatment plan.

Results: A comparison of the two applicator reconstruction methods did not show any significant differences in the calculated doses. Use of applicator library models over manual reconstruction resulted in the following dosimetry changes: There was a mean decrease of 0.043 Gy to the D90, 0.033 Gy to the bladder, 0.040 Gy to the intestines, 0.038 Gy to the sigmoid, and a mean decrease of 0.2% to the V100. The only organ at risk to receive an increase in dose was the rectum with a mean increase of 0.051 Gy.

Conclusion: These results show that the direct reconstruction technique yields equivalent dosimetry to the Applicator Modelling Library, which serves to validate its use as a clinically viable alternative.

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A DOSIMETRIC COMPARISON OF PROSTATE SEED IMPLANTS UTILISING EITHER A LOOSE SEED OR A STRANDED SEED TECHNIQUE

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Purpose: The seed implant technique in our hospital was recently changed from an intra-operative, loose-seed implant technique to an intra-operative, stranded-seed technique. As part of this change the standard prescription for a monotherapy implant changed from 160Gy to the prostate to 145Gy to a PTV comprising of the prostate plus a margin of 0.3cm left, right and anterior. Both techniques utilised the I25.S17plus Iodine–125 seed model.

The purpose of this study is to compare the dosimetry at day 0 and day 30 for the two implant techniques, and to determine if either of the techniques are associated with superior dosimetric outcomes.

Material and methods: The dosimetry for the most recent 20 loose seed monotherapy patients (introduced using a Mick applicator) was compared with the dosimetry for the first 20 monotherapy stranded patients (implanted using pre-loaded needles). Although the prescription for the stranded seeds is to the PTV, for the purposes of this study, values to the prostate were also recorded.

The following parameters were evaluated: Prostate V100, V150, and D90, and Rectum V100, based on day 0 (ultrasound) and day 30 (CT), along with the urethra D30 at Day 0 (ultrasound).

Differences in dosimetry at day 0 and day 30 were also compared for both cohorts.

Results: The dosimetry for both cohorts is broadly similar. Changing the prescription from 160Gy to the prostate, to 145Gy to the PTV has resulted in the following:

Mean stranded prostate V100 day 0 was slightly higher than loose prostate V100 day 0 (92.86% stranded, 91.92% loose) but the opposite was true at day 30 (91.98% stranded, 94.94% loose).

Similar trends were seen for the mean prostate D90 (day 0 169.87Gy stranded, 166.18Gy loose, and day 30 169.47Gy stranded, 175.54Gy loose).

The mean rectum V100 was lower for the stranded technique at day 0 (0.36Gy stranded, 0.48Gy loose) but slightly higher at day 30 (0.62Gy stranded, 0.52Gy loose)

At day 0, the mean urethra dose was lower for the stranded technique (176.04Gy stranded, 178.84Gy loose).

Conclusion: Prescribing 145Gy to the PTV is dosimetrically similar to prescribing 160Gy to the prostate. While stranded seeds allow for seeds to be placed outside the prostate in locations not available with loose seeds, this has not resulted in significant changes to the dosimetry. This study has confirmed that the stranded seed implant technique is acceptable for clinical use.

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OPTIMIZING VARIAN ECLIPSE RADIOTHERAPY TREATMENT PLANNING SYSTEM (TPS) ACUROS® XB DOSE CALCULATION ALGORITHM FOR SMALL FIELDS DEFINED BY MULTI LEAF COLLIMATOR (MLC)

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Objective: IMRT and SRT utilize small treatment fields, in contemporary treatment planning and for conventional linac they are delivered using MLC. TPS requires set of beam data measured by the user and other parameters to compose a calculation model for dose calculation. Varian Eclipse TPS AcurosXB dose calculation algorithm requires the user to input parameters like the effective target spot size and MLC DLG which then can be optimized to reach better agreement between calculated and delivered treatment plans.

Materials and methods: The spot size of the AcurosXB version 15.06.04 algorithm was adjusted to minimize the difference between calculated and measured test fields. Test fields were simple square shape fields collimated with MLC or jaws with different sizes, focusing on the smallest field size (1x1cm2). Test fields were measured with PTW T60019 microdiamond detector and with EBT3 radiochromic filmdosimetry on Varian Truebeam STx linac with beam energy 6 MV WFF, Varian 120 HD MLC. Measured data was compared with TPS calculated data with different beam configurations. Total of six different spot sizes and fifteen different DLG values were tested. Output factors, lateral beam profiles and penumbra width were compared, and gamma analysis made with the PTW Verisoft system.

Results: Starting position was spot size X=1.5 mm and Y=0 mm and DLG=0.37 mm, which provides gamma pass rate 73.2% (2% 1 mm). For 1x1 cm2 field with any spot size, the calculated dose by TPS is overestimated in the order of 10% compared with true dose measured with diamond detector. Based on lateral beam profiles, penumbras, and gamma analysis, three of the six different spot sizes provided better agreement: X=1.0 mm and Y=0 mm; X=1.0 mm and Y=0.5 mm; X=1.0 mm and Y=1.0 mm. None of them is the recommended value by Varian X=1.5 mm and Y=0 mm. For optimizing the DLG value, spot size X=1.0 mm and Y=0.5 mm was fixed. Taking into consideration the smallest field, 1x1 cm2, the best DLG would be 0.8 mm which is 116% different from DLG=0.37 mm value calculated from measured data. Spot size X=1.0 mm and Y=0.5 mm and DLG=0.8 mm provides gamma pass rate 93.3% (2% 1 mm).

Conclusion: In this work simple square MLC delimited fields were used to determine optimal spot size and DLG for Acuros XB algorithm using Varian Truebeam STx linac with 120 HD MLC and 6 MV WFF beam. The optimal spot size found is X=1.0 mm and Y=0.5 mm. The DLG calculated from measured data for linac used in this work was 0.37 mm; optimized DLG value 0.8 mm.

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VIABILITY EVALUATION OF THE SMART SEGMENTATION TOOL IN CLINICAL ROUTINE

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Purpose: The aim of this work is to study the viability of the Smart Segmentation tool (a fully automatic anatomy segmentation system for CT images) in the clinical routine.

Organ contouring is a time consuming task for radiation therapists, and therefore, automatic segmentation tools are being investigated.

Material and methods: Fifty five head and neck (H&N) CT sets were imported to our Smart Segmentation (SS) database as expert cases. Both parotids, spinal canal and mandible were already contoured by a radiation therapist and reviewed by a physician. SS algorithm will segment these organs in a new CT based on the expert cases.

Five already treated H&N patients were automatically contoured by the software, ranging from 2 to 10 expert cases with a 4 out of 5 in SS Similarity Index. In addition, two different radiation therapists re-contoured these five CT sets.

Three analyses were performed using Dice Similarity Coefficient (DSC). A DSC of 1 means complete overlap of contours and 0 no spatial overlap at all:

1. A comparison between organs contoured by a radiation therapist and organs contoured by SS were studied as a function of number of expert cases used.
2. Contour delineation made by two radiation therapists were compared to the one done by SS.
3. A comparison between organs contoured by radiation therapist #1 and by radiation therapist #2.

Results: On the first analysis, DSC showed a tendency to stabilize above a certain number of expert cases used: five cases were required for the parotids, two for the mandible and three for spinal canal.

On analysis two, SS achieved a DSC average value 0.11 lower for the parotids, 0.12 lower for the mandible and 0.03 lower for the spinal canal when compared with radiation therapist contourings.

On analysis three, the average DSC was 0.75 for the parotids, 0.86 for the spinal canal and 0.96 for the mandible.

Conclusions: Mandible and spinal canal SS segmentation showed higher DSC values than in parotids. These results were in agreement with radiation therapist contourings.

Using expert cases above a certain number showed no significant improvements in the DSC, only an increase in computation time.

This study concludes that SS can be introduced in the radiotherapy workflow with results similar to the ones achieved by radiation therapists and without any added risk, since a physician later reviews all the organ delineations.

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PROSTATE VMAT TREATMENTS: SINGLE-ARC VS DUAL-ARC METHOD

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Purpose: This retrospective study aims to compare the dosimetric difference between double- and single-arc planning method in the Volumetric-Modulated Arc Therapy (VMAT) prostate-cancer treatment. The plans quality was also evaluated.
Methods: Twenty VMAT prostate-cancer treatment plans, delivered by a Varian TrueBeam 2.7 with a MLC High Definition (HD 120), and performed at Humanitas Istituto Clinico Catanese (HICC), were selected. These Reference Plans (RPs) were calculated with the Anisotropic Analytical Algorithm (AAA), and a dose calculation grid size of 2 mm, using Eclipse v.15.6 Treatment Planning System (Varian Medical System). The patients were treated with a dose prescription of 2.7 Gy in 26 fractions, using 6 and 10 MV photon beams and two VMAT arcs: 150°-210° counterclockwise (CCW) and 210°-150° clockwise (CC).
The RPs were recalculated twice: using a partial single-arc (p-SA) from 150° to 210° CCW and a full single-arc (f-SA) from 181° to 179° CCW. All the optimization objects and all the plan parameters were left unchanged.
The plans quality was evaluated using the Conformity Index (CI) and the Homogeneity Index (HI). The dosimetric results were evaluated in terms of comparison between the dose-volume parameters obtained from the RP plans, and those obtained from the p-SA and the f-SA methods. The following dose-volume parameters were evaluated: mean dose (Dmean, Gy), V50Gy (%) and V20Gy (%) for bladder; Dmean (Gy), V40Gy (%), V50Gy (%) and V20Gy (%) for rectum; maximum dose (Dmax, Gy), Dmean (Gy) for femoral heads and V40Gy (%) (left and right separately).
Statistical analyses were performed to evaluate the differences between the two techniques.
Results: p-SA was able to achieve the best target coverage but the comparison with the RP, showed statistically significant differences for the rectum (V50Gy and V20Gy), and the right femoral head (Dmean and Dmax). No statistically significant differences were found between the dose volume parameters of the f-SA plans with respect to the RPs. Furthermore, f-SA and the RP methods lead to equal results regarding the target coverage. Therefore, the f-SA is preferred over p-SA technique.
Conclusions: Both f-SA and double-arc techniques are equivalent in terms of plan quality and dose-volume parameters, therefore these are good options for the VMAT treatment of the prostate cancer. Furthermore, f-SA plans can be delivered in shorter treatment times than the double-arc plans, leading to beneficial for the patients.

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COMMISIONING AND VALIDATION OF THE MONTE CARLO DOSE CALCULATION ENGINE OF A RAYSTATION TREATMENT PLANNING SYSTEM

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Purpose: The project was aimed at commissioning the Monte Carlo (MC) dose calculation engine of the Raystation v11A treatment planning system (TPS), already commissioned and in clinical use with the Collpased Cone (CC) engine.
Material and methods: The input data used to commission CC engine were used to obtain a MC model of a 6 MV (FF) photon beam generated by a Varian Trilogy TX linac. A number of validation tests were performed on the beam MC model that was found to fit better the data. The MC calculated dose distributions were checked in homogeneous and heterogeneous phantoms as well as in patient specific cases by dosimetric measurements and comparison with CC calculations.
Results: The MC was successfully modelled in the Raystation TPS. The validation test performed in water phantom showed an excellent agreement between MC calculations and diode measurements with deviations less than 1% both in-field and out-field and DTA less than 1 mm in penumbra region. Good agreement was found with the measurements in the PMMA-LUNG phantom containing lung and tumorlike inserts: the dose differences resulted below 2% between calculated and measured dose distributions. It is important to highlight that the Raystation MC engine calculates the dose in medium, without corrections it was observed that CC and EBT3 films overestimate dose in the order of magnitude of 3% to 5% in plexiglass, bone tissues and at the interface of lung/tumor or lung/plexiglass. Clinically, MC calculations was shown to be comparable with CC in homogeneous cases such as prostate, liver but a significant disagreement of the order of 5% arise when tissues of different densities are within the target, as observed in H&N, lung, and esophagus.
Conclusions: Monte Carlo dose calculation engine for a Raystation treatment planning system was successfully commissioned for clinical use . Apart from its well-known dose calculation accuracy in heterogeneous media, it also offers the much needed sparing-effects to organ at risk in clinical situations surrounded by the interface of high/low density organs. The study recommends that a careful consideration when using CC engine in certain clinical situations is needed during prescription and reporting dose as it tend to overestimate dose.

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QA MEASUREMENT OF THE LINAC GANTRY ANGLE USING PORTAL IMAGES OF A IN HOUSE DEVELOPED PHANTOM

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Purpose: According to AAPM TG 142 the digital Gantry Angle indicator has to have an accuracy within 1°. To execute this test in a fast and automized way a phantom was developed. The goal of this study is to show that by the acquisition and the evaluation of portal images of the phantom, the gantry angle for some cardinal angles can be determined.
Material and methods: The phantom consists of several ellipses made of steel of 5mm thickness with major and minor axis of 6cm and 2.5cm respectively, which are positioned in the Gantry rotation plane and are freely appended on a metal bar such that they are always pending in vertical direction. Due to geometrical considerations for a ellipse with a major/minor axis of 6cm/2.5cm the maximum increase of the projection length for a given $\Delta\alpha$ is given, if the ellipse is rotated by about 20° around the central axis respect to the infalling beam. To investigate the projection length of the ellipses respect to the gantry angle, images of five ellipses with 0°,-20°,-40°,-60°and 80° were acquired with a gantry angle around 0°. Image analysis was carried out with the IQworks v0.7.2 program using the FWHM parameter of the profile analysis.
Results: As expected the ellipse with a rotation of 20° respect to the infalling beam showed the steepest increase of the projection length with changing gantry angle. The projection length in mm versus the gantry angle could be described with the following linear regression line: y=0.4916*x+27.737 with an R^2 value of 0,9987.
Positioning the Gantry with a spirit level to 0° and repeating the acquisition five times by repositioning the phantom every time the evaluation gives a mean value of -0.11° and a standard deviation of 0.15°.

Acquiring portal images of the phantom with gantry angles 0°and 0.3° respectively and repeating the repositioning procedure for five times a paired t-test showed a p value of less than 0.01.
Conclusions: It was shown that using portal images of the in house made phantom it is possible to execute beam angle measurements with an accuracy sufficient to test the angle of the gantry according to the AAPM TG142 protocol.

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C-SPINE ALIGNMENT CORRELATIONS IN CYBERKNIFE TREATMENT SETUP

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Purpose: False node threshold is one of the most sensitive patient imaging parameters in Cyberknife C-spine setup. A node is identified as a false node if no correlation is found between the Live X-ray and DRR images. Threshold is set to allow 50% of the rejected nodes by default. That still challenging during treatment as this default threshold provide a possibility to damage vertebral anatomy especially for C-spine tumors. Hence, further investigation for this threshold-setup correlation is required to ensure sparing.
Materials and methods: Accuracy Head/Neck 6DSkull phantom has been used in this study. To simulate different patient setups, 1-path-body 91 setup plans was created using the available 7-head-rests which they have different angulations and elevations (Flat, A, B, C, D, E and F) ascending respectively. For every head-rest a range of threshold Mesh sizes (from 40 to 100 mm) was investigated, percentage of false nodes at Camera A and camera B was recorded accordingly. To eliminate any other affecting parameters, all setup corrections are kept below 0.2 mm, imaging parameters are kept at 120 KV and 100mA. The x-Axis Target Pairing Tolerance (dxAB) < 0.2 mm and the rotation Target Pairing Tolerance drAB<0.5 degree.
Results: Although most of institutions set the accepted of the false nodes to 15%, it's still site dependent according to available patient immobilization tools. For the accuracy phantom, results revealed three threshold zones (Green, Amber and Red) identified as (Go, attention and carful) zones respectively. The green, amber and Red zones are identified from 40 – 60 mm, 65 – 80 mm and 85 – 100 mm Mesh size respectively. For Green zone, the average percentage of the rejected nodes is 0.8% (SD=0.1) with max 4% mainly at C-type Head-rest, 60 mm mesh size on the B-camera. For the Amber zone, the average percentage of the rejected nodes is 8.3% (SD=3.8) with max 16% mainly with the Flat- and E- types Head-rests and 80 mm mesh size and both cameras. For the Red zone the average percentage of the rejected nodes is 16.6% (SD=0.1) with max 37% mainly with the Flat Head-rest on both cameras.
Conclusion: According to revealed results, head-rest as well as alignment mesh grid size choice highly affect treatment success. Both relatively low and high elevation head-rests (e.g. E and F types) may be not optima for C-spine cyberknife setup.

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PATIENT ALIGNMENT WITH AND WITHOUT SURFACE-GUIDED RADIOTHERAPY SYSTEM IN SRS TREATMENTS

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Purpose: Evaluation of set-up errors and efficiency of patients' positioning with lasers against Surface-Guided Radiotherapy (SGRT) system.
Material and methods: Twenty-Eight patients with brain malignancies treated with single-fraction SRS technique, using HyperArc algorithm, were retrospectively studied. Half of them were aligned with lasers according to the 3-point markers of the QFix Encompass immobilization system (Group_I) and the rest with AlignRT SGRT system (Group_II). Patient alignment was evaluated with Cone-Beam Computed Tomography (CBCT). The CBCT six-degree translational and rotational errors were recorded for each patient. The Root Mean Square (RMS) was calculated. The non-parametric Mann Whitney Wilcoxon test was performed for statistical analysis, using SPSS software Version 25.0. A level of p-value<0.05 was defined as statistically significant.
Results: The absolute median values for Group_I were 1.1 mm (0.6-2), 1.1 mm (0.1-2.7), 0.9 mm (0.4-1.7), 2.09 mm (1.14-2.93), 0.5° (0°-1.7°), 0.7° (0°-2.8°) and 0.6° (0°-2.5°) for vertical, longitudinal, lateral, RMS, pitch, roll and yaw, respectively. For Group_II the median values were, accordingly, 0.95 mm (0-3), 0.95 mm (0-3.9), 0.3 mm (0-1.3), 2.35 mm (0.54-3.96), 0.6° (0.1°-1.1°), 0.5° (0.1°-1°) and 0.6° (0.1°-1.1°). No statistically significant differences were observed between the two methods for set-up errors, except for lateral direction (p-value=0.002). For Group_I, in four cases the RTTs re-entered the treatment room to re-position the patients leading to the acquisition of at least two CBCTs. Specifically, two patients were re-imaged with two CBCTs, one with three and one with five. On the contrary, for Group_II only one patient was re-positioned a second time.
Conclusion: The SGRT system is reliable for patient positioning in SRS, having similar or better performance with the conventional laser alignment. In addition, the SGRT alignment technique proved to be more efficient than the 3-point markers one, in terms of the attempts required for the deltas to be acceptable.

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SECOND CANCER RISK FROM IMRT FOR WILMS TUMOR DURING CHILDHOOD: IS THE RISK HIGH IN RESPECT TO THAT FROM THE CONVENTIONAL IRRADIATION?

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Purpose: To assess the second cancer risk associated with the management of Wilms tumor during childhood using (a) the intensity modulated radiation therapy (IMRT), and, (b) the conventional anteroposterior (AP) and posteroanterior (PA) field technique.
Material and methods: This study was performed with two computational anthropomorphic phantoms. The phantoms represented the anatomy of a child aged 5- and 10-years-old. Two typical flank tumors located on the right and left side of each phantom were defined on a CT slice-by-slice basis by a radiation oncologist experienced in the treatment of abdominal malignancies. IMRT plans involving seven fields were generated for both tumor sites. Three-dimensional plans with an AP-PA field arrangement were also created. All plans were initially designed with 6 MV photons and, then, with 10 MV X-rays. Dose-volume histograms were employed to define the dose distribution of the liver and

small intestine from each treatment plan. The above dosimetric distributions were used together with the appropriate linear and non-linear models to assess the organ- and age-dependent risk of carcinogenesis.
Results: The excess absolute risk for liver cancer induction due to AP-PA field treatment of Wilms tumor varied from 0.2 to 1.0 cases per 10000 persons per year by the site of the primary disease, the photon energy employed and the patient's age. The probability of carcinogenesis to small intestine was 5.0-7.9 cases per 10000 persons per year. The risk for developing secondary liver and small intestine carcinomas following IMRT reached to 1.2 and 12.7 cases per 10000 persons per year, respectively.
Conclusions: The IMRT for Wilms tumor during childhood was found to lead to an increased risk for the development of liver and small intestine malignancies in respect to that associated with the conventional treatment technique.

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DOSIMETRIC COMPARISON OF PLANNING ON AN AVERAGE-CT VS. PLANNING ON A NORMALBREATHING-CT

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One way to improve the quality of radiation therapy of lung tumors is to monitor the patients breathing during the CT-scan of the patient. The CT-scan cycle can be partitioned into ten subscans each scanning the patient during a different phase in the breathing cycle. The mean of these subscans results in a so called Average-CT. This is in contrast to a Normalbreathing-CT where no partitioning of the breathing cycle during the image acquisition takes place.
We compare the dose differences of patient plans that are planned using an Average-CT and a Normalbreathing-CT. We calculate various dose measures such as the D2%, D90%, D95%, D98%, V100%, V95%, DHI-, HI and CI50%, CI80% and CI95%-index for the PTV, where DHI = D10%/D90%, HI = (D2% - D98%)/D50%, and CIdose = $Vdose^2$/(VPTV*Vdoseinbody).
Vdose is the volume of the corresponding isodose in the PTV and Vdoseinbody is the volume of the corresponding dose in the patient. Additionally, for the organs at risk i.e. lungs, heart and myelon dose-indices are evaluated.
We present a statistical analysis of the aforementioned dose quantifiers. In addition, the patients are divided into two groups: one with the irradiation site in a cranial position and one with the PTV in a caudal position in the lungs. Furthermore, the dose volume histograms of the PTV are shown for the patients. For patients where the dose levels are more strongly deviating, the movement of the PTV is discussed in selected CT slices.
Overall, we find that for cranially positioned tumors the relative difference in the dose quantities of the Average-CT and Normalbreathing-CT is on average within the range of 5%. However, for caudally positioned tumors the mean values of the relative differences show larger discrepancies. For example, the relative difference in the V100% is 27% with a standard deviation of 36%. In the most extreme case one patient exhibits a relative difference of 100% in the V100% due to the influence of the motion of the diaphragm which overlaps the PTV.

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INTER AND INTRA-FRACTION MOTION IN 3-FRACTION SBRT FOR PROSTATE CANCER: DOSE DEVIATIONS IN ORGANS AT RISK

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Purpose: In 15 patients out of 53 enrolled in a prospective study of SBRT for prostate cancer, the impact of organ motion on the delivered dose on OARs has been investigated.
Material and methods: Patients were prescribed 40Gy/3 fractions to deliver at least 36 Gy to 95% of the prostate while respecting dose constraint on OARs; rectal D1cc<30Gy; bladder D1cc<38Gy, urethra D0.1cc<33Gy. Fiducials markers, urethra catheter and rectal spacer were placed. Treatments were delivered by a VMAT 10 MVFFF technique; CBCTs were acquired before treatment (initial), between each arc and at the end of the treatment (final). CBCT images were aligned to planning CT based on both catheter and fiducials positions. No correction for rotation was applied. After CBCT HU calibration, original plans were recalculated on both the initial (after set up correction) and the final (after the end of treatment) CBCT for each patient/treatment session. Inter and intra fraction deviations were evaluated. Selected dose/volume metrics of OARs were extracted from the DVHs of the various plans and compared; the Mann Whitney test was used to assess the significance of the differences observed ($p \leq 0.05$).
Results: *Inter-fraction:* Doses calculated on CBCT initial were statistically different from the planned ones. Median plan D1cc rectum (Gy), D1cc bladder (Gy) and D0.1cc urethra (Gy) were 29.8, 37.8 and 24.7 respectively. Median initial D1cc rectum (Gy), D1cc bladder (Gy) and D0.1cc urethra (Gy) were 30.9, 38.9 and 33.8 respectively.
Intra-fraction: Doses calculated on CBCT final were not statistically different from the initial ones. Median final D1cc rectum (Gy), D1cc bladder (Gy) and D0.1cc urethra (Gy) were 30.2, 39.0 and 34.1 respectively.
Conclusion: Doses calculated on initial CBCT are higher than the planned ones, this systematic trend could be due to differences in calculation between CT and CBCT images and inaccuracy in CBCT calibration. However, ΔD ranges from 1.15 to 2.25 Gy for the whole course of treatment. Not significant differences between doses calculated on CBCT final and CBCT initial indicate that intra-fraction motion is not an issue provided the use of urethra catheter, fiducial markers, rectal spacer and a fast delivery technique.

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6 MV VS. 10 MV PHOTONS IN PELVIC VOLUMETRIC MODULATED ARC THERAPY: THE BOWEL DOSE

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Purpose: We evaluated the impact of choosing different photon energies (6 MV and 10 MV) for patients with pelvic lymph nodes included in the planning target volume (PTV) and treated with volumetric arc therapy (VMAT). In general, using 10 MV is considered advantageous for deep-seated targets; however, the deeper penetration in tissue together with the increased penumbra might sum up in higher bowel dose, when PTV dose coverage is maintained. Hypothetically, patient size could affect the result: the thinner the patient, the less advantageous using 10 MV would be.

Material and methods: We retrospectively studied 20 patients, who had received external-beam radiotherapy in pelvis due to gynecological cancer (Group 1: 10 patients, Varian Truebeam) or prostate cancer (Group 2: 10 patients, Elekta Axesse or Versa HD). All the treatments were performed using two full-arc VMAT fields, and the treatment plans were generated using Eclipse treatment planning system (Acuros XB, Version 16.1.0).
To compare the photon energy effect, each clinical plan was re-calculated with unchanged optimization parameters. The organs-at-risk (OAR) considered were bladder, rectum, femur heads, bowel bag, and sacrum. The OARs were delineated with artificial-intelligence-driven autosegmentation using MVision software (MVision AI). To study the patient size effect, the maximal anteroposterior and lateral diameters of the body were measured within the PTV region. The plan quality was estimated with minimum D(VPTV=98%) and maximum dose D(VPTV=2%) in the PTV, the mean doses to the OARs, and the volume of bowel receiving 15 Gy or more (V15). Also, the mean body dose and the plan monitor units (MU) were compared. All parameters were tested with paired samples t-test between each 6 MV and 10 MV plan.
Results: The only statistically significant differences observed between 6 MV and 10 MV plans were in the mean dose to bowel bag and body, and MUs required (for all, $p<0.001$). For Group 1, the mean dose to bowel bag was 1.9% and to body 3.6% higher, and 11% more MUs were used in the case of 6 MV than 10 MV. For Group 2, respectively, 2.1% and 2.8%, with 6% more MUs. No correlation between these parameters and the patient size was found.
Conclusions: We observed a minor difference in the plan quality in favor of 10 MV compared to 6 MV in pelvic VMAT: lower mean dose to bowel and body with less MUs employed, and thus, shorter treatment time.

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EVALUATION OF THE EFFECT OF SILICONE IMPLANTS IN A BREAST RADIOTHERAPY TREATMENT WITH MONTE CARLO SIMULATION

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Purpose: This study aimed to investigate the effect of silicone breast implants when they are submitted to radiotherapy with a treatment with 6 MV photon beam, using Monte Carlo simulation (MCNP 6.2 code) and a female anthropomorphic phantom (FASH3). The goal was to verify the scattered radiation by the silicone prosthesis through the absorbed doses in organs and tissues in comparison with the normal tissue of the breasts.
Material and methods: The MCNP 6.2 Monte Carlo code was used to simulate a radiotherapy scenario, modeling the room structure and a Varian 2100C LINAC, together with a female anthropomorphic phantom (FASH3) designed to be a patient with body mass of 60 kg, height of 163 cm and 113 important anatomical structures for dosimetry, such as organs, tissues and bones. The PDMS silicone material used for the breast implant was coupled to FASH3 in the left breast to simulate the dose distribution during breast radiotherapy treatment with a 6 MV photon beam, with a total dose of 50.4 Gy. Percentage depth dose curves (PDD) and dose profiles (Off-axis) were used to validate the simulation scenario, comparing those results with measurements obtained experimentally.
Results: Good correlations were obtained between the PDD and the off-axis simulated by the MCNP and those measured experimentally, with uncertainties lower than 2%. For the lateral external incidence, the right breast and left lung had the highest absorbed dose values. The gallbladder and bone surface achieved an increase of 1.3% for this incidence, with the silicone implant. The effect of silicone on medial internal incidence had a increase of 1.5% in the dose to the lens, followed by red bone marrow with a increase of 1.4. For this projection, the patient's organs with the highest absorbed dose contributions were the left lung and lymph nodes. During the entire treatment, the organs with increasing in the dose values were: the gallbladder (+1.4%), red bone marrow (+1.3%), bone surface (+1.3%), muscle tissue (+1.3%) and left lung (+1.2%).
Conclusion: The results showed that the silicone implant submitted to radiotherapy treatment caused a slight increase in the absorbed dose in the organ/tissues when compared to results obtained with normal tissue of the breasts.

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ACCURACY OF THE DOSES COMPUTED BY THE ECLIPSE TREATMENT PLANNING SYSTEM NEAR AND INSIDE METAL ELEMENTS

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Introduction: Metal artefacts degrade clinical image quality which decreases the confidence of using computed tomography (CT) for the delineation of key structures for treatment planning and dose errors in affected areas. In this work we investigated accuracy of doses computed by the Eclipse treatment planning system near and inside metallic elements for two different computation algorithms. In addition, an impact of CT metal artefact reduction methods on the resulting calculated doses has also been assessed.
Material and methods: A water phantom including Gafchromic film and metal inserts was irradiated (max dose 5 Gy) using a 6 MeV photon beam. Three materials were tested including titan, alloy 600, and tungsten. The phantom was CT imaged using the iterative (iMAR) and the pseudo-monoenergetic reconstruction (PMR) metal artefact reduction. Image sets were used for dose calculation using a treatment planning station. Monte Carlo (MC) simulations were used to predict the true dose distribution in the phantom allowing for comparison with film and CT doses.
Results: Measured and simulated percentage depth doses (PDDs) were not statistically different ($p>0.618$). Regional differences were observed at edges of metallic objects (max 8% difference). However, PDDs simulated with and without film conditions were statistically different ($p<0.002$). PDDs calculated by the Acuros XB algorithm based on the dose-to-medium approach best matched the MC reference regardless of the CT reconstruction methods and inserts used ($p>0.078$). PDDs obtained using other algorithms significantly differ from the MC values ($p<0.011$).
Conclusions: The Acuros XB algorithm with a dose to medium approach can be used for reliable dose calculation at all metal regions when using the Varian system. The inability of the AAA algorithm to model backscatter dose significantly limits its clinical application in the presence of metal. No significant impact on the dose calculation was found for a range of metal reduction strategies.

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RISK ORGAN DOSE REDUCTION OR TARGET DOSE ESCALATION WITH ISO-EFFECTIVE AND ISO-TOXIC ADAPTIVE RADIOTHERAPY FOR STAGE III NSCLC

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Purpose: Despite advances with the introduction of immunotherapy, only 40% of patients with locally advanced non-small-cell lung cancer (NSCLC) will reach 5-year overall survival. Survival may improve by increasing the radiation doses, which are frequently limited by the maximum lung and heart tolerance doses and their related toxicities. The current radiotherapy workflow often neglects tumor regression and other morphologic changes. The purpose of this work is therefore to compare different strategies of daily offline adaptive radiotherapy (ART) and their impact on relevant dose-volume metrics.

Methods: Thirteen treatment series of patients with NSCLC stages III-IV were retrospectively analyzed. Prescription doses were 60 Gy (11 patients), 58 Gy (1 patient) and 56 Gy (1 patient) with daily fractional PTV-D95%-doses of 2Gy. Daily cone-beam CTs for all treatment fractions (n=387) were converted into synthetic CTs (sCTs) using a cycle-generative adversarial network. Image segmentation was performed on all datasets independently. GTV-volumes were determined in the first- and last-fraction-sCTs. Initial treatment plans (TP) (220° dual arc VMAT) were created on the first-fraction-sCTs to minimize potential deviations due to sCT generation errors. These TPs were subsequently transferred unaltered to the sCTs of the remaining fractions of each patient (f2-fn) (IGRT-scenario). Furthermore, two further TPs were generated for the fractions f2-fn of each patient: one minimizing lung dose while preserving the PTV-D95% (iso-effective) and one escalating the PTV-D95% with a constant ipsilateral lung-V20Gy (iso-toxicity). The three cumulative dose distributions were compared regarding the following dose-volume parameters: ipsilateral lung-V20Gy and -mean dose (MLD), heart-V5Gy and -mean dose (MHD), GTV-D95% and PTV-D95%.

Results: The mean last-fraction-GTV-volume was 59.7%±15.8% of the first-fraction-GTV-volume. Compared to the averaged predicted dose of the initial TPs, following relative dosimetric changes occurred:

- Without adaptation GTV-coverage remained adequate (D95%=99.5%±3.4%), while the PTV-D95% decreased to 94.1%±11.7%. Organ at risk (OAR)-doses were higher than predicted (lung-V20Gy=106.2%±13.0%, MLD=105.6%±10.9%, heart-V5Gy=105.2±24.9%, MHD=109.3%±29.8%).
- The iso-effective scenario restored the GTV- and PTV-doses (GTV-D95%=100.3%±1.4%, PTV-D95%=100%±0.0%) and minimized cumulative OAR-doses (lung-V20Gy=90.1%±9.8%, MLD=93.1%±8.2%, heart-V5Gy=93.5±24.6%, MHD=94.0%±22.9%).
- With iso-toxicity prescription, a dose escalation to the GTV (D95%=119.6%±19.0%) and PTV (D95%=112.7%±16.5%) without increased OAR-doses was feasible (lung-V20Gy=100%±0.0%, MLD=101.1%±9.2%, heart-V5Gy=96.3±24.9%, MHD=102.7%±26.6%).

Conclusions: Without ART, morphologic changes during RT result in increased OAR-doses during the treatment period. Translated into clinics, ART could positively influence on reducing secondary events, while enabling dose-escalation strategies and therefore improve outcomes of patients with NSCLC. Translation to clinical benefit is subject to recent research.

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ANALYSIS OF DOSE CALCULATION USING LESION TO ISOCENTER DISTANCE AND PTV SIZE

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Purpose: Nowadays, treatments of small lesions with high prescription doses that require high precision when reproducing treatments are becoming more frequent. Sometimes these treatments include several lesions and divergence of radiation beams becomes relevant. It may not be calculated with sufficient accuracy by the treatment planning system. With this analysis we aim to evaluate how the size of the lesion and its distance from the isocenter affects dose calculation.

Material and methods: To perform this, spherical PTVs of 1, 3, 6 and 10cm^3 are generated in the contouring module (Eclipse v 15.6 treatment panning system) on the CT images of Iba Dosimetry Easy Cube phantom. For each PTV, three DCA (Dynamic Conformed Arc) and VMAT (Volumetric Modulated Arc Therapy) plans are generated by locating isocenter at different distances from PTVs (0, 5.2 and 8.7cm). These plans are calculated with different DLG (Dosimetric Leaf Gap) values (0.05, 0.12 and 0.1359 cm). Finally, absolute doses of these fields are measured with an Easy Cube phantom from Iba Dosimetry and a PTW pinpoint ionization chamber in the TrueBeam accelerator equipped with MLC Millennium 120.

Results: The results of analyzing DCA plans indicate that dose difference can increase up to 1% between measuring plans with isocenter inside or outside the PTV. The variation in the DLG value does not affect at all. For all cases, the measured dose is higher than the calculated one.

For VMAT treatment plans, a dependence on the distance to the isocenter is also observed, with an increase in doses differences up to 6.7%. For these cases, variation in DLG parameter has an important effect, obtaining the most concordant calculations for a value of DLG of 0.12cm.

For DCA and VMAT plans 1cm^3 volume is the most affected by distance to isocenter and the variation in DLG.

Conclusions: The size of the lesion and its distance from isocenter can affect the correct dose calculation of the treatment planning system. The correct choice of DLG value can help in the accuracy of the calculation, but it is not enough to correct possible variations with the distance from the lesion to the isocenter.

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RADIOLOGICAL AND DOSIMETRIC PROPERTIES OF A 3D-PRINTED BOLUS COMPARED TO THOSE OF A PATIENT-SPECIFIC PASTE-FORMAT BOLUS AND A TRADITIONAL ONE

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Purpose: The use of bolus is a traditional technique for treating superficial lesions in radiotherapy. A new bolus, Simple Bolus (Adaptiiv Medical Technologies Inc., Halifax, Canada), enable users first to create patient-specific bolus by using 3D printing software and second to track it with a surface-guided radiotherapy system, SGRT (VisionRT, AlignRT Ltd, London). This study compares Simple Bolus properties to eXaSkin (Anatomical Geometry SL., Sevilla) and Superflab (Eckert and Ziegler BEBIG GmbH, Berlin) properties. EXaSkin is a patient-specific paste-format bolus while Superflab (Eckert and Ziegler BEBIG GmbH, Berlin) is a traditional sheet bolus.

Material and methods: We perform this study using 1cm thickness Simple Bolus sample, one Superflab sheet 1cm thick sample and an eXaSkin made-bolus approximatively 1cm thick. We scan samples with SOMATOM go.Open Pro CT (Siemens, Germany). We perform scans with 0.6mm thickness to study material radiological properties and we perform scans with clinical protocol thickness (3mm) to study material dosimetric properties. Radiological properties are not assessed for eXaSkin as it depends on user. To check radiological properties we quantify material uniformity, noise and difference between measured and theoretical material Hounsfield units (HU). To check dosimetric properties, we study consistency between AAA dose calculations (Eclipse, Varian, PaloAlto SA) and plastic water dose measurements at depths 2, 3, 4, 5, 8, 10cm.
Results: Uniformity and noise for Simple Bolus and Superflab samples are respectively 17% and 0.3%, 40% and 0.6%. Absolute difference between measured and theoretical UH is 20UH and 77UH for Simple Bolus and Superflab respectively. Maximum and mean difference found between calculated and measured doses for the Simple Bolus, eXaSkin and Superflab samples are 0.4% and 0.1%, 0.8% and 0.4%, 1.9% and 1.3% respectively.
Conclusions: Simple Bolus showed slightly better radiological properties than a traditional bolus as Superflab. Furthermore, dosimetric properties show 1% better consistency than other kind of specific-patient bolus as eXaSkin. Simple Bolus not only is the only bolus that can be purely SGRT tracked but also shows better agreement that other specific-patient bolus.

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KNOWLEDGE-BASED (KB) MODEL FROM SINGLE PATIENT INTER-FRACTIONS ADAPTIVE MAGNETIC RESONANCE GUIDED RADIOTHERAPY (MRGRT) PLAN

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Purpose: To assess the possibility to use different plans from the same patient obtained in the frame of the MRgRT, where dose distribution is daily adapted on the patient's anatomy.
Materials and methods: Ten patients treated in a 0.35T MR-LINAC for locally advanced pancreatic cancer (LAPC), have been enrolled. Patients received 40 Gy in five fractions, prescribed to the 80% isodose line. For each patient a nominal dose distribution has been optimized on the planning MRI, fused with a planning CT acquired the same day. Each fraction has been daily adapted if needed: clinical and planning target volume (PTV) have been daily re-contoured, as well as organs at risk (OARs). Plan re-optimization has been performed to shape dose distribution on the daily anatomy, considering the clinical OARs constraints. Each plan has been then exported from the MR-LINAC treatment planning system and employed for KB model generation (RapidPlan, Varian). The following OARs have been included in the model: aorta, bowel, colon, duodenum, spinal cord, stomach and inferior vena cava. The goodness of the model has been evaluated by checking the coefficient of determination (R^2) and the average Pearson's chi-square (χ^2) of fit statistic for each OARs. Preliminary investigations on regression plots have been performed, especially on the duodenum since it is the most critical OAR in terms of plan daily adaptive optimization. As a result, a R^2 value ≥ 0.6 is considered acceptable in terms of prediction performances.
Results: From the ten enrolled patients, fifty-one plans have been included in the model generation: 9 fractions have been not adapted since the anatomical variation was not relevant in terms of dosimetric variation and therefore clinical constraints were within tolerance. Considering OARs modeling, R^2 values are always higher than 0.6: aorta=0.94, bowel=0.63, colon=0.80, duodenum=0.94, spinal cord=0.62 stomach=0.81 and inferior vena cava=0.95. OARs' χ^2 values range between 1.08 and 1.2 meaning that the patient's statistics are consistent. Further regression plots analysis have been performed between: duodenum geometric distribution principal component score 1 vs DVH principal component score 1 (R^2= 0.69); PTV volume vs duodenum DVH principal component score 1 (R^2= 0.61).
Conclusions: KB model generation based on patients' inter-fractions plans results to be able to provide suitable modelling for patients with LAPC treated with MRgRT. These preliminary results are strongly encouraging for the implementation of the KB-approach during the daily adaptation of the plan.

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EVALUATION OF CBCT-BASED SYNTHETIC CTS FOR CLINICAL ADOPTION IN PROTON THERAPY OF HEAD AND NECK PATIENTS

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Purpose: In adaptive proton therapy, weekly verification CTs (rCTs) are commonly acquired and used to monitor patient anatomy. Cone-Beam CTs (CBCT) on the other hand are used for daily pre-treatment position verification. These CBCT images however suffer from severe imaging artifacts preventing accurate proton dose calculations, meaning that CBCTs are unsuitable for treatment planning purposes. Recent advances in converting CBCT images to high quality synthetic CTs (sCTs) using Deep Convolution Neural Networks (DCNN) show that these sCTs can be suitable for proton dose calculations and therefore assist clinical adaptation decisions. The aim of this study was to compare weekly high definition rCTs to same-day sCT images of head and neck cancer patients in order to verify dosimetric accuracy of DCNN generated CBCT-based sCTs.
Materials and methods: A dataset of 46 previously treated head and neck cancer patients was used to generate synthetic CTs from daily pre-treatment patient alignment CBCTs using a previously developed and trained U-net like DCNN. Proton dose was then recalculated on weekly rCTs and same-day sCTs utilizing clinical treatment plans. To assess the dosimetric accuracy of sCTs, dose to the clinical target volumes (CTV D98) and mean dose in selected organs-at-risk (OAR; Oral cavity, Parotid gland left, Submandibular gland right) was calculated and compared between rCTs and same-day sCTs. Furthermore, Normal Tissue Complication Probability (NTCP) models for xerostomia and dysphagia were used to assess the clinical significance of dose differences.
Results: For target volumes, the average difference in D98% between rCT and sCT pairs (N=284) was 0.34±3.86% [-0.18±2.06 Gy] for the low dose CTV (54.25 Gy) and 0.23±3.62% [-0.16±2.48 Gy] for the high dose CTV (70 Gy). For the OARs the following mean dose differences were observed; Oral Cavity: 4.15±9.78% [0.75±1.39 Gy], Parotid L: 5.34±11.6% [0.58±1.40 Gy], Submandibular R: 2.17±8.55% [0.55±2.57 Gy]. The average NTCP difference was -0.15±0.58% for grade 3 dysphagia, -0.26±0.54% for grade 3 xerostomia, -0.53±1.20% for grade 2 dysphagia and -0.71±1.40% for grade 2 xerostomia.
Conclusion: For target coverage and NTCP difference, the deep learning based sCTs showed high agreement with weekly verification CTs. However, some outliers were observed (also indicated by the increased standard deviation) and warrant further investigation and improvements before clinical implementation. Furthermore,

stringent quality control tools for synthetic CTs are required to allow reliable deployment in adaptive proton therapy workflows.

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DOSIMETRIC CONSIDERATIONS DURING RADIOTHERAPY TREATMENT PLANNING COMPUTED TOMOGRAPHY SIMULATION SCANS

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Purpose: Computed Tomography (CT) scanning is an integral process of the radiotherapy treatment planning procedure. Although, compared to the radiotherapy (RT) doses, the radiation doses from CT simulation scans are relatively small, the principle of optimization requires that they must also be kept as low as reasonably achievable. The scope of this study was to collect and process dosimetric data from several CT simulation scans and to investigate whether there is potential for meaningful dose reductions.
Material and methods: CT simulation scans from 63 average-sized patients (20 prostate, 22 breast and 21 lung cancer patients) referred for RT at the AHEPA University Hospital were included in the study. All scans were performed on a General Electric RT LightSpeed CT scanner, using the standard department protocol. Appropriate dose metrics (CTDIvol, DLP) were collected for all scans from the system dose report. A Varian Eclipse and an Electa Monaco TPS were used to define treatment planning volumes (GTV, CTV, PTV and OARs) and to calculate RT dose distributions. For each scan, the distances of the scan limits from the uppermost and lowermost outlined volumes, as well as from the 10% isodose surface were calculated. Considering a minimum margin of 2cm on both sides, necessary for accurate dosimetry calculations, the possibility of dose reduction by limiting the scan length was investigated and its significance on organ doses was estimated using the ImPACT CT Dosimetry (version 1.0.4) software.
Results: CT scan length could be reduced on average by 16%, without compromising target organ delineation and dosimetry calculations, leading to an equal percent reduction in CT scan DLP. The reduction was more prominent for prostate cancer (20%) followed by breast cancer (14%) and lung cacer (14%) patients. Optimizing CT simulation scans in prostate patients could lead to a reduction in intestine dose by 19% and in gonad dose by 27%. For breast cancer patients, thyroid doses could be reduced by 56% and bone marrow doses by 9%. For lung cancer patients, thyroid doses could be reduced by 38% and bone marrow doses by 10%.
Conclusions: Significant percent dose reductions to sensitive healthy organs could be achieved by careful optimization of CT simulation scan limits. Special care should be taken not to over-restrict CT scan length which could lead to repeating the simulation scan. In absolute numbers the dose savings maybe small, but not negligible, since the principle of optimization still applies.

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AN ANALYTICAL APPROACH TO MONITORING CLINICAL PATIENT SET-UP TOLERANCES IN SURFACE GUIDED RADIOTHERAPY (SGRT)

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Purpose: Surface guided radiation therapy (SGRT) is a valuable tool for accurate patient positioning during breast cancer radiotherapy and its use has become more widespread in recent years. Essential to the implementation of SGRT is the correlation between SGRT treatment offsets and offsets determined by cone-beam computed tomography (CBCT). Tolerances used in SGRT systems largely rely on vendor recommended values for a given treatment site. For example, default tolerances for breast setup using SGRT systems is commonly set at ±3mm. The purpose of this study is to evaluate the potential of using a data driven method to monitor and optimise site specific tolerances for SGRT-only setups.
Methods: Patients undergoing right and left whole-breast radiotherapy in deep inspiration breath hold (DIBH) were setup with AlignRT (VisionRT, London, UK) and their position verified by CBCT. Localisation accuracy was defined as the difference between the SGRT treatment offsets (delta values) and CBCT offsets. Localisation data consisting of 226 treatment fractions of lateral, longitudinal and vertical translations were reviewed. Statistical tolerance intervals were established to define the upper and lower translational values in which 95% of the population would fall.
Results: The study showed the efficacy of using tolerance intervals to monitor and update SGRT delta values for patients undergoing radiotherapy for breast cancer. Preliminary results analysed during the early adoption of SGRT highlight that default setup tolerance values are perhaps too strict. As staff confidence in the system increases, local data-driven tolerance values can be established for each translational offset.
Conclusion: A data driven approach was used to establish the relationship between current departmental SGRT tolerances and historical pre-set tolerances, with the intention of updating the SGRT delta values if required. Updating the setup tolerances to department-specific and site-specific values is of particular importance after initial implementation of SGRT, when confidence in the system and competency of staff using the system increases. Further work will be carried out to establish tolerance values for more treatment sites.

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EVALUATING H&N IMMOBILISATION USING DEFORMABLE IMAGE REGISTRATION

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Purpose: The primary aim of this MSc study is to investigate using deformable image registration (DIR) to assess immobilisation for patients undergoing external beam radiotherapy for head and neck (H&N) cancer and to choose one or more quantitative metrics based on TG-132 (Brook et al. 2017) to assess immobilisation performance. A significant difficulty encountered when treating this site is changes to the anatomy, with weight loss and independent movement of organs at risk, bony anatomy and the target(s) occurring, meaning that rigid registration between the cone-beam computed tomography (CBCT) and planning CT (pCT) scans cannot adequately describe the motion.
Material and methods: Within our centre, the standard method of immobilisation is a five-point shell with an open mouth. There have been four other pilot studies conducted over a number of years that investigated different modes of immobilisations. The five study groups were:

- Five-point shell with an open mouth (20 patients)
- Five-point shell with a closed mouth (19 patients)
- Five-point shell with mouth bites (20 patients)
- Five-point shell with hand grips (17 patients)
- Three-point shell with hand grips (12 patients)

Velocity (Varian) will be used for DIR between the on-treatment CBCT and the original pCT volumes. TG-132 has suggested the use of the DICE similarity coefficient, the mean distance to agreement and analysis of the Jacobian of the deformation vector field as metrics that may be used. By calculating these metrics for each patient for easily identifiable regions of interest, such as the mandible, spine and occipital bone, the performance of an immobilisation device can be assessed and therefore comparison of different immobilisation devices can be made directly.

Results: Preliminary results were obtained by considering the on-treatment daily couch shifts in the lateral (x), vertical (y) and longitudinal (z) axes. The five-point shell with an open mouth group had systematic errors in mm of (1.3, 1.5, 1.1) and random errors of (1.2, 1.1, 1.1). As a representative example, the three-point shell group had errors of (0.7, 0.9, 0.9) and (2.6, 1.6, 1.2).

Conclusions: Translational shifts found all modes of immobilisation performed equally well. The MSc project will ascertain a DIR metric to better describe the independent motion of bony anatomy within the immobilisation devices. The most effective immobilisation will be the device that achieves the minimal motion relative to the pCT.

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QA FOR THE CLINICAL IMPLEMENTATION OF KV INTRA-FRACTION MONITORING USING NOVEL 3D PRINTED PHANTOMS

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Purpose: Intra-fraction prostate motion remains an uncertainty that is typically accounted for, enlarging prostate CTV-PTV margins. Varian TrueBeam v2.5+ have an Auto-Beam-Hold (ABH) system which provides real-time intra-fraction motion monitoring. ABH uses 2D planar kV images to detect implanted fiducial markers throughout treatment. Fiducials are permitted to move within a deviation limit (DL), beyond which the MV treatment delivery is paused. Commissioning of alternative tracking software has been reported in the literature(Ng et.al 2014, TG147 2012) however, detail of the commissioning, accuracy and precision of the ABH system is lacking. The aim of this project was to commission the ABH system. Novel 3D printed phantoms were designed and implemented to this aim and will be presented.

Material and methods: The Ultimaker S5 3D printer was used to print three phantoms; A 3D cylindrical phantom designed to fit within the commercially available 'Quasar' Phantom to assess static and dynamic tracking; A custom 3D pelvis phantom(Giacometti et al 2021) 'ELVIS', water filled with bone-equivalent anatomy to assess tracking in clinical conditions; and a simple block phantom combined with a programmable moving platform designed for daily radiographer QC. All phantoms had gold fiducial markers inserts, as will be used clinically.

The 2D planar kV image field size, dose and image quality were optimised by measuring contrast to noise ratio (CNR) of the fiducials in the ELVIS phantom. The ABH detection accuracy and precision was tested using the Quasar phantom in a single direction, couch translations in 3 directions and when using typical prostate patient trajectories. Daily radiographer QC to test the ABH system was designed and implemented.

Results: A 6x6cm^2 kV imaging field size was optimal based on previous patient's fiducial implants. Set exposure of 110kV/10mAs provided an appropriate balance between CNR values and imaging dose, even when imaging through dense pelvis anatomy.

The QUASAR phantom movement accuracy was 0.48±0.12mm. The couch translations had an average accuracy of 0.02±0.07mm across all axes.

The detection accuracy of the markers was ~66% due to issues detecting fiducials perpendicular to the direction of image acquisition. The accuracy of the MV beam on and off was 100% both for the couch movements and the patient trajectories with a precision of ≤±0.5mm. The daily radiographer QC test correctly demonstrated the operation of the ABH system to ≤1mm within a 3-minute test.

Conclusion: The precision and accuracy of the ABH system has been determined using novel printed phantoms.

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THERMO-RADIOTHERAPY TREATMENT: A SYNERGISTIC APPROACH TO TREAT SUPERFICIAL SOFT TISSUE SARCOMAS EVALUATED BY DYNAMIC CONTRAST ENHANCED MAGNETIC RESONANCE IMAGING (DCE-MRI)

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Purpose: The aim of this work is to evaluate the combination of radiotherapy and hyperthermia (RT-HT) in superficial soft tissue sarcomas (SSTS). Loco-regional hyperthermia i.e increasing tumour temperature to 39°C-43°C, is a radio-chemio sensitizer which has been shown to be effective in cancer treatment. However, RT-HT is affected by several factors, e.g. heating duration, time order and interval between RT and HT, etc. A clinical protocol approved by our ethics committee has just begun to evaluate pre- and post-treatment data by advanced MRI imaging.

Materials and methods: Two patients with pleomorphic lypo-sarcoma and myxofibrosarcoma have been enrolled in the protocol so far. Patients underwent a baseline and post-treatment magnetic resonance (MR) 3T exam with DCE-MRI to evaluate perfusion maps, such as Ktrans which represents the constant rate from the vascular to the extracellular-extravascular space, by the extended Tofts model. In addition, a whole body CT-PET with 18F pre and post treatment were performed. RT Treatments consists of a 6MV VMAT photon beams irradiation, with a preoperative dose of 50 Gy at 2 Gy/fraction administered 5 days a week. Locoregional HT is performed immediately after RT by a radiative antenna at 434 MHz. Ktrans has been calculated inside lesions by distinguishing hypovascularized volume from Gross Tumour Volume (GTV).

After treatment, the patient with pleomorphic liposarcoma presents an increase in median values of both GTV (from 90 to 114 cm^3) and hypovascularized volume (from 33.7 to 73.3 cm^3 and in Ktrans from 1.03 to 0.30 min^(-1), while the patient with myxofribosarcoma presents decreased GTV (from 11.3 to 7.6 cm^3) and Ktrans (from 0.20 to 0.14min^(-1)).

Conclusions: Patient accrual is ongoing, these preliminary results show that DCE-MRI is a potentially helpful tool to monitor modifications in tissues after treatment. Metabolic data from PET should improve the accuracy of volumetric maps.

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OPTIMIZATION OF THE LUNG SHIELDING IN TBI PROCEDURE

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Purpose: Total Body Irradiation (TBI) relies on providing an acceptably uniform dose to the body while sparing the critical organs. Different strategies of lung tissue shielding to reduce the risk of radiation pneumonitis are applied among institutions performing TBI. Because they usually result in under dosage of the chest wall, the dose is usually supplemented with electron beams. According to the ILROG guidelines, using an additional inner margin between the edge of the lung shadow on the radiograph and the shield edge may improve the dose homogeneity in the chest wall area. Our purpose was to determine the optimal value of the applied margin taking into account the need for a compromise between the lung volume receiving the full dose and the ribs volume exposed to the prescribed dose from the photon beam.

Materials and methods: An anthropomorphic phantom was irradiated on a TrueBeam linear accelerator with 6 MV photon beam using extended SSD TBI technique. Based on the radiographic image four lung shields were prepared with various widths of unshielded tissue strip between the shield edge and the edge of lung shadow (0, 0.5, 1, 1.5 cm). Gafchromic EBT 3 dosimetric films were placed between the phantom slabs in the middle part of the lung. The dose images were analyzed using ImageJ software to determine the dosimetric and anatomical relationships under the applied shielding conditions. Moreover, to obtain the volumetric information, a treatment planning system with CT reconstructions was applied. TPS was also used to simulate various shielding strategies for clinically treated cases.

Results and conclusions: As revealed from the measurement results for the margin 0 cm, the shielded part of the lung is 91% (2D) and 81% (3D) of its measured surface and calculated volume, respectively. Every 0.5 cm change in the margin was found to induce an additional 10% of the lung volume and 10-15% of the ribs volume to be exposed. The decrease in the dose from 90% to 10% of the prescribed dose in the area of the shield shadow took place over a distance of 8 mm (average value), which did not depend on the shielding strategy used. The measured distance between 50% dose and the edge of the lung agreed well with the planned margin. The maximum thickness of the chest wall requiring additional irradiation with the electron beams was found to decrease with the increase of the applied margin.

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SUITABILITY OF A 3D PRINTABLE MATERIAL FOR DOSIMETRIC EVALUATION OF IORT TREATMENTS

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Purpose: Intraoperative Radiotherapy (IORT) delivers a high dose of radiation in a single fraction during a surgical procedure with direct access to the tumor bed, minimizing the absorbed dose in normal tissue. With this technique, images of the patient are not acquired and therefore treatment planning is not possible. Thus, it is necessary to approximate dose calculations on flat surfaces, which differ from real irregularities of surgical beds.

The aim of this work is to analyse the suitability of a 3D printable material in order to perform a more realistic post-treatment dosimetric evaluation of IORT treatments.

Material and methods: A mixture of styrene-butadiene synthetic latex and carbon was used to print the phantom in several sheets of different thickness, conforming a cylindrical shape of 20 cm of radius. The density of material is 1,027 g/cm^3 and it is printed with a DT600+ 3D printer from Dynamical Tools with a fill density of 100%. A slight warping of sheets and grooves were observed in printed phantom. The electron accelerator for intraoperative therapy was the LIAC HWL (Sordina IORT Technologies, Vicenza, Italy).

The central axis percentage depth dose curve (PDD) was measured using the 60 mm diameter and flat-ended polymethylmethacrylate applicator and 8 MeV beam energy. Radiochromic Gafchromic EBT3 films were used for the measurements. The electron beam Monte Carlo (MC) simulation software SWL-LIAC Monte Carlo Simulation provided the profiles and PDD calculations used in the analyses.

Results: The experimental PDD was represented graphically and compared with PDD calculated by MC. Both curves were normalized to the maximum dose. For depths less than R_{50} mm, experimental data (coverage factor k=2) were consistent respect to MC. However, for greater depths, experimental PDD curve was an overestimation of the MC PDD curve. Relative percentage differences of R_{50}, R_{20} and R_{10} between the experimental and MC results were 8.7%, 10.5% and 17.1%, respectively.

Conclusion: The phantom composed of a mixture of styrene-butadiene synthetic latex and carbon is not suitable for a realistic post-treatment dosimetric evaluation of IORT treatments because it is not consistent with MC results.

Currently, measures of the distribution of the absorbed dose in the transverse axis of radiation beam at different depths are being carried out in order to obtain more information about the suitability of this material.

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DRIFT AND ROOM LIGHT INTENSITY EFFECT ON EXACTRAC DYNAMIC PREPOSITIONING SYSTEM: A PHANTOM STUDY

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Purpose: The Brainlab Exactrac Dynamic (ED) is a Surface and Image Guided Radiotherapy system, which pre-positions the patient by matching the live 3D surface with the patient external contour and

then uses stereoscopic X-Ray images to achieve the final positioning based on internal anatomy.
According to Brainlab, the Surface Guided prepositioning system can work in three different states of warm-up (A, B and C), which depend on the power on time, both of the whole system and the structured light projector. These different states could result in a different pre-positioning of the patient. Furthermore, the accuracy of the system can be affected by the treatment room light intensity. The aim of this work was to evaluate the drift effect due to the warm-up time and the room light intensity effect, both on the surface prepositioning system.
Material and methods: The ED system incorporated in a Varian TrueBeam STX accelerator was tested using the Daily Check phantom and the Daily Check Test (DCT) procedure, which analyses the consistency between the X-ray and the 3D Camera isocenters. This consistency check is considered out of tolerance when the resulting displacement vector is greater than 1 mm.
Drift effect was evaluated performing the DCT three times in the three states of warm-up of the system.
Room Light intensity effect was evaluated performing the same DCT with the room light on and off (three times each), measuring the light intensity with a Delta-Ohm HD2302.0 luxometer.
Results: The average displacement vectors between the X-ray and the 3D camera isocenters for the warm-up states A, B and C were: A=1.42±0.06 mm, B=0.24±0.07 mm and C=1.53±0.08 mm (k=1).
A difference of 0.11±0.03 mm (k=1) was calculated between the average displacement vectors obtained for this consistency with a light intensity of 317±7 lux (light on) and 7.8±0.4 lux (light off).
Conclusions: A displacement out of tolerance in the DCT is observed for warm-up states A and C. This could be explained because the calibration of the system was performed in the B warm-up state, in which the system usually works.
Despite Brainlab recommends using the ED prepositioning system with the room light off, we have observed a very low dependency of this system in the range of the light intensity studied in this work.

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DETERMINATION OF SET UP ERRORS AND PLANNING MARGINS ON PATIENTS SUBJECTED TO IMAGE GUIDED RADIOTHERAPY: A CLINICAL STUDY FOR PROSTATE, THORACIC AND HEAD AND NECK CANCER

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Purpose: The purpose of this study was to compare the positioning accuracy using two-dimensional kilovoltage (2D-kV) and three-dimensional Cone Beam Computed Tomography (3D-CBCT) imaging in patients undergoing Image Guided Radiation Therapy (IGRT) in order to determine the planning margins for prostate, thoracic and head and neck anatomical sites.
Material and methods: Shifts in the left-right (LR), superior-inferior (SI) and anterior-posterior (AP) directions were recorded with both imaging techniques for 39 patients in total, with prostate, lung and head and neck tumors. The 2D-kV Images were acquired daily, while the 3D-CBCT images were acquired daily for the first three sessions and every five sessions then on. Systematic and random set-up errors were estimated for both imaging methods, in order to calculate the planning margins using the Van Herk equation $M=2.5\Sigma+0.7\sigma$. Moreover, statistical analysis (paired sample t – test) was used to determine whether the differences between the two imaging methods were statistically significant for each anatomical region. Differences in shifts larger than 1mm were considered clinically significant.
Results: Statistically significant differences ($p<0.05$) in shifts based on 2DkV and 3D-CBCT images were observed for almost all anatomical sites and for all directions, however they were not all considered to be clinically significant. In the prostate region, the mean differences in LR and SI directions were 0.3mm ($p=0.007$) and 0.4mm ($p=0.007$) respectively, whereas the mean difference in AP direction was 1.3mm ($p<0.001$). In the thoracic region the mean differences in the LR and AP directions were 1.1mm ($p<0.001$), and 1.9mm ($p<0.001$), respectively, whereas the mean difference in the SI direction was 0.1mm ($p=0.657$). Finally, in the head and neck region, all mean differences were clinically significant, being 1.1mm ($p=0.013$), 1.3mm ($p<0.001$), and 1.5mm ($p<0.001$), in the LR, SI and AP directions respectively. The set-up margins calculated based on the observed shifts for the two imaging modalities (2DkV/3D-CBCT), were 7.4/8.3mm (AP), 6.9/6.6mm (SI) and 8.3/7.9mm (LR) for the prostate PTV, 5.6/6.4mm (AP), 6.7/5.8mm (SI) and 5.7/6.8mm (LR) for the lung PTV and 5.2/5.9mm (AP), 2.7/5.8mm (SI) and 2.8/7.4mm (LR) for the head and neck PTV.
Conclusions: The calculated set-up margins based on both imaging modalities were similar for the prostate and the thoracic regions and compatible with those suggested in the literature. Further investigation is required in the head and neck region, where reproducibility in patient set-up is more challenging.

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ADAPTING MATERIAL DECOMPOSITION ACQUISITIONS FOR DECT CALIBRATIONS IN PROTON THERAPY PLANNING

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Purpose: Proton therapy planning requires estimating proton range, which depends on physical properties of the material. Converting CT image values to physic properties (calibration) is a source of uncertainty due to the SPR dependence on electronic density and atomic number. This can be reduced by imaging with two X-ray energies, better characterizating tissues and leading to more accurate SPR estimates.
Dual-energy CT (DECT) allows acquiring images using two different energies in the same procedure/study, reducing acquisition time, patient exposure and motion artifacts. Single source DECT (ssDECT) from General Electric (GE Healthcare, Waukesha, WI, USA) offers a material decomposition map (MDM) and Virtual Monochromatic Images (VMI); however, VMI do not directly correlate with single-energy CT (SECT), and its use for calibration is not straightforward.
Thus, we aim at reducing uncertainty by adapting MDMs from ssDECT to derive diagnostic low and high energy images used as input for calibration methods.
Materials and methods: We used a GE REVOLUTION CT scanner, with SECT and ssDECT protocols, and a GAMMEX multi-energy CT phantom conformed by tissue surrogates mimicking the real body tissues.
The equation presented in the American Association of Physicists in Medicine (AAPM) report 291 contains all required information to derive high and low energy images from MDMs. The information is satisfied acquiring two sets of SECT data (80kvp and 140kvp) and one DECT providing an MDM (iodine-water) for the calibration of the scanner.

After calibration, high and low energy images can thus be derived from the MDMs. The generated images are analysed using the tissue surrogates of the phantom. Mean ± standard deviation of the derived CT image values was computed for each tissue surrogate and compared to the actual composition of the surrogates based on the SECT high and low energy images.
Results: Our results show no real differences for water and iodine surrogates between the SECT and images derived from the MDM. However, differences for the other tissues exist, requiring further improvement. Preliminary results show that our method presents better performance than VMI reconstructed from MD in most cases.
Conclusions: We presented a novel approach to adapt DECT calibration methods that use high and low energy images to ssDECT scanners that offer an MDM as output. These phantom study results should be validated with biological tissues and compared to existing DECT calibrations to test their potential use in clinical workflows.

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ROBUST OPTIMIZATION IN CRANIOSPINAL PATIENTS
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Purpose: In plans with multiple isocenters, fields are overlapped to increase robustness with respect to misalignement errors. The new version of Varian's Photon Optimizer (PO, 16.30) introduces an autofeathering option, which smoothes fields in the junction area. The purpose of this report is to evaluate the dosimetric consequences of this new feature.
Material and methods: A craniospinal (CSI) patient is considered, with two isocenters. A non-robust plan is compared to a new plan using the autofeathering option. In order to evaluate robustness, misalignement errors are introduced in the superior-inferior direction, of 5 mm. Dose is recalculated for 12 treatment scenarios, and the width of dose-volume histograms (DVHs) is compared.
Results: Dose profiles show a smooth gradient in the field junction region when the autofeathering option is used. When misalignements are considered, we observe an improvement with respect to the dosimetric parameters: maximum dose is reduced, nd the width of DVH bands is narrowed. Dose uniformity is also improved, reducing the amount of hot and cold spots in the PTV.
Conclusions: The autofeathering option leads to plans that have better robustness with respect to positional errors. This is particularly useful in patients with multiple isocenters, which usually lead to further misalignement errors in the treatment room. The reduction of maximum dose is especially significant for serial organs, as is the case for CSI patients.

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INVESTIGATION OF DOSE RESPONSE IN POLYMER GEL 3D/4D DOSIMETRY
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Purpose: to investigate photon irradiated nMAG (methacrylic acid in gelatin) gels dose response in four-dimensional (4D) absorbed dose distribution and to measure limitations and sensitivity of gels by Magnetic Resonance Imaging technique.
Materials and methods: The nMAG gel dosimeters were prepared in a normal oxygen environment. 8% gelatin was mixed with distilled water and heated to 45 °C until the gelatin was completely dissolved. Then the solution was cooled to 32 °C, and 8% methacrylic acid was added and stirred for 25 min. Tetrakis(hydroxymethyl) phosphonium chloride (THPC) was added as a deoxidant. After preparation gels were poured in to plastic 100 ml container. After preparation gels were stored in cool dark closed until irradiation.
nMAG gels radiation were performed by Varian Truebeam linear accelerator. 6 MeV FFF (flattening filter free) beam energy were used with maximum dose rate 1400 MU/min from 5 Gy to 50 Gy dose. Radiation field was formed 4 cm2. To simulate the 4D absorbed dose motion simulator was used where the mechanical design was used to simulate movement- a rotating elliptical disc moving a hinged platform. The main platform travel no more then 4 centimeters from its lowest to its highest point along a vertical axis.
Magnetic resonance imaging (MRI) was performed on the irradiated gels to create R2-dose response curves.
Results: The visual analysis of nMAG gels showed that the radiation induced polymerization and crosslinking originates in irradiated gels. The polymerization occurred in the region of irradiated volume along a vertical axis and the concentration increased where the dose was higher. The results in a reduction of spin relaxation times (T1 and T2) of hydrogen nuclei in the aqueous gel showed great evaluation to obtain precise 4D dose distribution of polymer gel dosimeters with high spatial resolution. When polymer gels are irradiated there is a variation in mobility of surrounding water molecules which results in alteration of spin lattice relaxation rate R1 (=1/T1) and spin relaxation rate R2 (=1/ T2). R2 is more sensitive to dose response then R1.
Conclusions: Gel dosimetry is a powerful tool to measure four-dimensional (4D) dose distribution for complex delivery verification and quality assurance for the lung cancer patient radiotherapy treatment taking into account the breathing movement.

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FORMULAS FOR CALCULATING THE BIOLOGICALLY EQUIVALENT DOSE BASED ON THE IDEA OF TUMOUR CONTROL PROBABILITY
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Purpose: Making a number of mathematical models which explain empirically obtained results for tumor control probablity in external beam radiotherapy.
Methods and materials: A comparison between the "single hit-multiple target" model and the "linear-quadratic" model has been made fitting an empirically obtained data for the tumor line HT-29 in the work of Nahum and Hill with both models separately. All the results have been represented graphically using the Matlab 4.0 software product.
Results: Formulas have been derived that connect the main values characterizing a given modality of external beam radiotherapy - number of fractions, dose per fraction and total dose. The dependences given by equations 4.2.2, 4.2.3, 4.2.5, 4.2.6 in case of neglect of repopulation and those 4.4.4, 4.4.5, 4.4.12, 4.4.13 taking it into account, represent the full set of relations to recalculate the values determining one fractional regime in another, if the probability of tumor control is determined by the Poisson distribution.

4.2. Formula for recalculating the fraction dose leading to the same BED for two fractional regimens, without taking into consideration the tumor repopulation constant λ:
4.4. Formula for recalculating the fraction dose leading to the same BED for two fractional regimens, in the case of a repopulating tumor, with repopulation constant λ:
It is presented how the probability of tumor control of TCP at different doses per fraction and for different values of repopulation rate λ = 0.04, λ = 0.12 and λ = 0 changes based on the dependence D (d) for λ = 0.
It has been represented experimental data for HDR-brachytherapy of prostate tumor for 20 patients recalculating the corresponding dose chart for the 2Gy fraction using the α/β ratio for prostate tumor equal to 3Gy.
Conclusions: The calculations derived, allow ranking and selection of radiation treatment and help to deliver different doses in different volumes of the tumor and saving the surrounding risk organs. The importance of the inclusion of repopulation in the formulas for TCP and BED is shown in different graphics. A great impact towards the most accurate estimate of tumor control is observed, especially for tumors with a large proliferation constant.

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THE POTENTIAL FOR ORGAN-AT-RISK SPARING WITH NON-COPLANAR DYNAMIC-COLLIMATOR TRAJECTORY RADIOTHERAPY (COLLI-DTRT) FOR HEAD AND NECK CANCER

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Purpose: To evaluate the potential for organ-at-risk (OAR) sparing with non-coplanar dynamic-collimator trajectory radiotherapy (colli-DTRT) compared to coplanar-VMAT, using optimized table angle, gantry-angle range, and dynamic collimator rotation.
Material and methods: Gantry-Table cost-maps quantifying target/OAR overlap in beam's-eye-view were used to optimize the number of arcs, their table angle, and gantry-angle range for colli-DTRT. Candidate arcs spanning more than 50° gantry-angle range on the thresholded cost-map are ranked by cost (lowest to highest) and gantry-angle range (longest to shortest). Final selection is based on summed ranks and user-defined desired total gantry-angle range. Dynamic collimator rotation is determined to minimize field width in the x-direction. colli-DTRT partial arcs are imported in a research version of the Eclipse treatment planning system for intensity modulation optimization (Varian Medical Systems).
colli-DTRT was compared to coplanar-VMAT for seven head-and-neck (HN) cases on an anthropomorphic phantom. Delivery times, including time between arcs, were estimated based on the maximum speed of the linac components. One colli-DTRT plan was delivered to a water-equivalent cubic phantom with two interleaved films on TrueBeam linac.
Results: All plans had acceptable target coverage. Mean dose to salivary glands, pharynx and oral cavity was reduced by 2.2 Gy on average with colli-DTRT compared to VMAT for three locoregionally advanced oropharyngeal carcinomas and one adenoid-cystic carcinoma (all sequential boost). D0.03cc to optic nerves (ON, tolerance: 54 Gy) was 54.8 Gy (VMAT) and 53.1 Gy (colli-DTRT) for left-ON and 31.4 Gy (VMAT) and 19.0 Gy (colli-DTRT) for right-ON for a nasopharyngeal carcinoma. Mean dose to the contralateral vocal cord and arytenoid were reduced by 4.4 and 9.8 Gy respectively with colli-DTRT compared to VMAT for a single vocal cord irradiation. D10% to the contralateral carotid PRV (tolerance: 15 Gy) was 15.5 Gy (VMAT) and 8.5 Gy (colli-DTRT) for a stage-II laryngeal carcinoma.
The average [min-max] gantry-angle range of colli-DTRT was 349.2° [295.2°-392.4°] per full VMAT arc (360°), using 2.8 [2.0-3.5] partial arcs. colli-DTRT had 1.54 [1.15-2.06] longer estimated delivery times than VMAT. Comparison of the measured film-dose with the calculated dose (Analytical Anisotropic Algorithm, Varian) resulted in gamma passing rates (global, 2%/2mm, 10% threshold) of 100% and 99.2% for the coronal and sagittal planes respectively.
Conclusion: There is substantial potential to reduce OAR dose with optimized table angle, gantry-angle range and dynamic collimator rotation compared to VMAT. colli-DTRT can be efficiently and accurately delivered on conventional linacs.
This work was supported by Varian Medical Systems.

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PROOF OF CONCEPT OF SURFACE MONITORING FOR DYNAMIC TRAJECTORY RADIOTHERAPY

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Purpose: To demonstrate time-resolved surface monitoring during dynamic trajectory radiotherapy (DTRT) for table rotation verification and intrafraction motion monitoring and to assess its accuracy.
Methods: DTRT exploits additional beam directions to improve plan quality by extending VMAT with dynamic table and collimator rotation during beam-on. A surface-monitoring-system using three cameras (SMS, IDENTIFY™, Varian Medical Systems) is employed during delivery of five DTRT plans. The DTRT plans cover each a full gantry rotation combined with different table rotations.
Two experiments are conducted: First, spheres on both sides of a head phantom were used to monitor and record the table-rotation-angle at 5 Hz. The accuracy of the table-rotation-angle monitoring was assessed by comparison of the table-rotation-angle recorded in the treatment machine logfile to that of the SMS-logfile using root-mean-square-error (RMSE).
Second, styrofoam spheres on a moving phantom with peak-to-peak amplitude was 1.5 cm (vertical), 0.4 cm (longitudinal) and 8° (pitch-rotation), were used for intrafraction motion monitoring. Motion along the other axes was below 1 mm/1°. Accuracy was quantified by comparing motion during DTRT delivery to motion recorded with static table (reference) using RMSE. To explore the lateral and roll axes, the experiment was repeated with the phantom rotated by 90°.
Results: Time-resolved surface monitoring was obtainable for all investigated DTRT plans and phantoms, without loss of signal at any gantry-table angle combination. Table-rotation-angle monitoring had an RMSE 0.32° for the first experiment. For table rotation verification, investigations with different setups of the spheres concluded, that it is necessary to have trackable surfaces on both sides of the head model, to guarantee that at least two cameras have continuous sight of parts of the phantom. The second experiment had an RMSE for motion monitoring of 0.49 mm (vertical), 0.27 mm (longitudinal), 0.37° (pitch-rotation), and, for the 90° rotated phantom 0.70 mm (vertical), 0.28 mm (lateral),

0.52° (roll-rotation). Monitoring of the phantom rotation (reference motion below 1° peak-to-peak) due to table rotation was compared to treatment machine recorded table rotation resulting in a RMSE of 0.21° and 0.22° with the rotated phantom.
Conclusion: Time-resolved surface monitoring was successfully demonstrated with sub-mm and sub-degree accuracy to verify table rotation and to monitor intrafraction motion. This work was partially supported by Varian Medical Systems.

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QUANTITATIVE ANALYSIS OF DATA VARIABILITY IN DELINEATED TARGET VOLUMES FOR THE LEFT BREAST WITHOUT LYMPH NODES CASE
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Purpose: To analyse the similarity characteristics of the delineated target volumes by the different radiation oncologists for the left breast without lymph nodes patient.
Materials and methods: There was created a reference delineation plan according to the ESTRO guidelines for the left breast cancer without lymph nodes patient with a diagnosis of a high-grade nuclear polymorphism in situ component of infiltrative ductal carcinoma. The patient's target volumes (CTV_WB and PTV_WB) and the other related structures (heart, spinal cord, lung_ipsilat) were delineated by 14 different radiation oncologists. In order to determine the extent of variance in CTV_WB and PTV_WB contouring, the Dice Coefficients (DICE) were determined and analysed using an open-source software "EvaluateSegmentation" and treatment planning system "Eclipse". Additionally, using an open-source software "EvaluateSegmentation" were determined and evaluated Jaccard Coefficient (JAC), Area under ROC Curve (AUC), Cohen Kappa (KAP), Rand Index (RI), Adjusted Rand Index (ARI), Interclass Correlation (IC), Volumetric Similarity Coefficient (VSC) and Mutual Information (MI) coefficients.
Results: The analysis of the similarity characteristics of the structures (CTV_WB and PTV_WB) revealed that the results obtained with the treatment planning system "Eclipse" and the "EvaluateSegmentation" software for Dice coefficients were similar and differed as follows: CTV_WB (0.88 a. u. ÷ 0.96 a. u. (Software) | 0.91 a. u.÷ 0.96 a. u. (Eclipse)) and PTV_WB (0.86 a. u.÷ 0.96 a. u. (Software) | 0.85 a. u. ÷ 0.97 a. u. (Eclipse)). It is known that the closer the delineated volume is to the reference volume, the higher obtained value of the coefficient is determined (ideal case – the value is equal to 1). Additionally, to the DICE, other similarity coefficients like JAC, AUC, KAP, RI, ARI, IC, VSC and MI were studied using an open-source software "EvaluateSegmentation", and it was determined that it could be successfully used as an extra tool for the similarity characteristics analysis.
Conclusions: Analysis of similarity characteristics showed variability in delineation, due to this reason it is important to ensure that target volumes (and organs at risk) were delineated according to a certain protocol. Otherwise, this might have a significant influence on the final prescription of the dose and the organs at risk received dose.

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IS REPLANNING REALLY NECESSARY FOR HDR VAGINAL BRACHYTHERAPY?
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Purpose: Vaginal HDR Brachytherapy is used in endometrial cancer after total hysterectomy to vaginal cuff, to prevent the recurrence, delivered in 7Gy×3 fractions, prescribed at 5mm depth from vaginal surface, when used alone, or in 2-3 fractions of 4-6 Gy when used as a boost to EBRT. A 3DCT scan for contouring, planning, and dosimetric evaluation is performed in each session. Our purpose is adjusting the first session's treatment plan to the following, without performing a new CT and plan, by validating the applicator's position stability.
Materials and methods: 28 patients were selected (ages 40-80), with total hysterectomy followed by postoperative vaginal brachytherapy using a cylinder applicator, delivered in 2-3 sessions. Three parameters were examined: the angle between the catheter axis and pubic symphysis (Φ), the distance between the catheter tip and right and left acetabulum, respectively (D1, D2). By calculating the deviation of those parameters for each patient and each session, we determine the existence of a significant displacement factor. Furthermore, in 10 cases, the first session's plan was used and adjusted for the Ir-192 decay, as an alternative in performing a new plan for the following sessions. We targeted, thus, to calculate and compare the dosimetric factors of the studied structures to predict and validate our hypothesis.
Results: It was observed that Φ deviated by an average factor of 2.45% between patient's sessions and distances D1 and D2 by an average factor of 1.76% and 2.68% respectively, proving no significant catheter displacement throughout patient's sessions. Our dosimetric study resulted in small variations in the contoured structures. The relative dose of the PTV(final) in 90% volume presented a deviation factor of 1.88% and 2.96% from the completed 1st and 2nd - 3rd fraction plans, respectively. The absolute absorbed dose of the OARs, Rectum, Bladder, and Bowel, at 2cc volume, deviated by a factor of 4.41%, 5.17%, and 3.85% from the original plans while each organ meets the dose constraints.
Conclusion: Geometric deviations arising from the applicator insertion, during the 2nd and 3rd session and evaluation of dose differences for tumor and OARs, conclude that our hypothesis to use the first session's plan for the following sessions is safe and practical. The radiation oncologist estimates issues that suggest a new plan for the following sessions. Additionally, using the first plan only has more advantages: less CT dose, less capital cost, faster, more efficient, and easier for the patient.

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USE OF EPID FOR DOSIMETRIC PRE-TREATMENT VERIFICATION OF FFF VMAT FIELDS
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Purpose: To evaluate the use of aS1200 electronic portal imaging device (EPID) dosimetry with VMAT flattening filter free (FFF) beams for patient-specific pre-treatment quality assurance.
Material and methods: The behavior of the aS1200 EPID of a TrueBeam STx (Varian Medical Systems, USA) for 6 MV FFF beams has been analyzed. The maximum active field size of aS1200 EPID is 40×40 cm^2, with a pixel size of $(0.336)^2$ mm^2. The aS1200 has advanced acquisition electronics for fast image readout to avoid the high dose-rate saturation effect. Inside this EPID, there is a lead plate to reduce backscatter from the arm, reducing this effect, compared to previous models.
Several tests have been performed for characterization of this EPID: linearity of the signal versus monitor units (MU) and dose rate (up to 1400 MU/min), long-term stability for a period of 14 months, ghosting effect, dependency on field size, dependency on source-to-detector distance (SDD), and the influence of the arm on backscatter radiation.
VMAT QA was performed for 12 clinical cases. The predicted dose images were calculated with Raystation (Raysearch, Sweeden) treatment planning system (TPS) and corrected by an in-house program. The EPID was modeled as a phantom with slabs of different densities in the TPS and our program includes output factors and corrections for backscatter and SDD. This modelling was tested by gamma comparison of the dose calculated images versus the measured EPID dose images.
Results: For the linearity with MU, we obtained differences below 0.8%, larger differences corresponded to less than 10 MU. Linearity with dose rate was within 1.4%. Good long-term stability is obtained (differences of 1% over 14 months) and a negligible ghosting effect (differences below 0.5%). The field size dependence is similar to the ionization chamber measurements. Dose dependence on SDD was below 1%. Regarding to arm-backscatter radiation, we found that the profile asymmetry along the longitudinal axis was less than 0.4%.
To evaluate VMAT plans, corrections were applied to the dose planes extracted from the TPS, and compared with the measured planes. Gamma test (2%/2 mm, with a threshold of 10%) produces gamma index above 96.2%. Better gamma were obtained using a SDD of 150 cm.
Conclusions: EPID dosimetry is an attractive method for routine use due to its fast setup, easy data acquisition, and high spatial resolution. The results obtained in this work support its use for VMAT pre-treatment dosimetry, preferably at 150 cm SDD.

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USING A PULSE COUNTING CIRCUIT TO CONTROL AN ULTRA-HIGH DOSE-RATE ELECTRON BEAM, FROM A MODIFIED COMMERCIAL C-ARM LINEAR ACCELERATOR

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Purpose: FLASH radiotherapy exploits ultra-high dose-rates (UHDR); ~100 times greater than conventional treatments. FLASH has gained significant interest from publications showing favourable biological outcomes – specifically reducing normal tissue toxicity, for equivalent tumour control. This may allow for isotoxic dose escalation regimens, particularly for more radioresistant tumours.
At UHDR, ion chambers cannot be used reliably and linac internal monitor chambers cannot be used to control the exposure. Alternative methods are required. This study seeks to establish whether a pulse counting circuit can robustly control an UHDR, MeV electron beam produced using a modified Varian Clinac iX linear accelerator.
Materials and methods: A clinically decommissioned linac was locally converted to produce UHDR electron beams, by removing the flattening filter and target from an MV photon setup. The internal monitor chamber was disconnected. A pulse counting circuit with an added relay was connected to the linac's beam-hold PCB, in order to trigger a beam-hold at a programmed number of delivered pulses. Prior to the linac conversion, control using the pulse counter was verified by comparison with conventional monitor chamber control. Repeat exposures were delivered (without dose-rate servos) to investigate the repeatability. The relationship between PFN and target pulses was also investigated, comparing charge delivered across a 20-36000 pulse range.
Post linac conversion, without the photon target, the pulse counter can only count PFN pulses. Therefore, the derived PFN-target pulse relationship could be used along with Gafchromic film and TLD point dose measurements to estimate dose per pulse.
Results: The pulse counter circuit was found to effectively control the beam, with differences <0.5% in charge delivered compared with the linac monitor chamber, rising to 1.5% for small exposures (10 MU).
Without dose servos, output repeatability tests yielded a standard deviation of 6% at conventional dose-rates, rising to 18% at UHDR.
It was not possible to robustly account for the initial linac ramp-up period - leading to variable PFN pulses that did not result in a delivered radiation pulse. This uncertainty had a subsequent effect on output variation.
The conversion resulted in a ~200 Gy/s electron beam, and dose per pulse was measured as 1.30±0.14 Gy and 1.10±0.08 Gy using film and TLD's respectively.
Conclusions: A Varian Clinac iX linac can be effectively converted to produce UHDR electron beams. Retrofitted pulse counting controllers can be used to beam-hold after a required number of pulses. Further work is required to resolve issues with output repeatability.

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IMPROVING IRRADIATION EFFECTS ON A RADIORESISTANT MELANOMA CELL LINE USING ANTI-MALARIAL DRUGS

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Purpose: To improve the effectiveness of rapid irradiation on a radioresistant melanoma cell line, a synergistic effect of two antimalarial drugs with radiation is investigated. The goal is to present a method for conducting a reduction in the antioxidant properties of these cells and improving the radiotherapy results.
Material and methods: A radioresistant murine melanoma cell type (B16) was received from the Pasteur institute research center in Tehran, cells were maintained in Dulbecco's Modified Eagle Medium, supplemented with 10% heat-inactivated fetal bovine serum and 1% penicillin-streptomycin. Cultures were incubated at 37°C in a humidified incubator with 5% CO2. Cells were subjected to experimental treatments at 70-80% confluence. Cell suspensions were plated (200 µL/well) into 96-well at-bottomed plates and they were incubated for four hours to adhere in a humidified atmosphere with 5% CO2 at 37°C to perform appropriate and efficient cites for a various range of drug concentrations, and an acceptable repeat condition.

Pills of both drugs (Chloroquine and Hydroxychloroquine sulfate) were purchased and solved in distilled water to a final concentration of 1mg/mL. X-ray radiation was applied using a linear accelerator (Elekta Synergy platform); a 25*25 cm^2 field was opened to deliver 4-Gy and 6-Gy homogenous doses with 6 MV and 8 MV respectively, as was advised by studies.
Different concentrations of drugs were added to plates 24 hours before the irradiation. There were two study groups (24h and 48h after irradiation), each including five subjects of study (drug treatments only, 4-Gy irradiation only, 6-Gy irradiation only, 4-Gy irradiation + drug treatment, 6-Gy irradiation + drug treatment), each subject at each group was repeated 3 times for statistical analysis. Twenty-four and forty-eight hours after irradiation, 100 µL (5mg/mL) was withdrawn from each well, 10 µL MTT solution was then added to each one, plates were incubated for about three hours at 37°C, 100 µL of DMSO was added to each well afterward, and finally, absorbance was recorded at 570 nm.
Results: When radiation alone was used on the cells, no certain effect was observed. When each of the drugs was used alone on a 25 µg/mL concentration, about 50% survival was reached (suggesting the LD50). When the same concentration was combined with a 6Gy rapid irradiation, survival rates were decreased to under 20% after 48 hours.
Conclusion: The mentioned types of oxidant antimalarial drugs enhance the efficacy of rapid irradiation on a highly radioresistant melanoma cell line.

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3D PRINTING IN RADIOTHERAPY – A SURVEY OF UK AND IRELAND

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Purpose: The purpose of this survey was to assess the current 3D printing activity in radiotherapy departments in the UK and Ireland.
Material and methods: A link to the survey was posted on the UK (Medical-Physics-Engineering) and Irish (Irish Association of Medical Physicists) medical physics mail-bases as well as being distributed electronically to radiotherapy physics leads in UK radiotherapy (RT) departments. The survey was designed to establish patterns of practice with respect to 3D printing applications and associated hardware, software and quality assurance (QA).
Results: We received responses from 65 RT departments, with 25 (39%) RT departments currently using 3D printing. Of the remaining 40 departments, 85% proposed that they would or may use 3D printing within the next 3 years. 3D printing was primarily utilized for phantom construction (45%) and creating bolus (34%). There were 17 different printer types within the RT departments although the primary type was fused deposition modeling (FDM). Similarly, 11 different slicing software types were used although most utilized Ultimaker (38%) or IdeaMaker (21%). In the extraction of data from DICOM files for printing, there was a mix of commercial and paid software. PLA is the material most used to 3D print bolus whereas a wide range of materials was employed for creating phantoms. Over 80% of departments verify the geometric accuracy of prints. Risk assessments had been performed in 56% of RT departments and 64% have established a QA program. However, only 36% use 3D printing followed the HSC RR1146 guidelines [1].
Conclusion: A significant proportion of RT departments employ 3D printing technology or intend to employ this technology in the future. A wide range of software and hardware combinations is employed to create 3D prints, primarily for bolus and phantom development. Many RT departments have not yet performed a risk assessment, commissioned a QA program or follow the HSC safety guidelines. This survey has given a view into the landscape of 3D printing activity in the UK and Ireland and has established that guidance on implementation and maintenance of 3D printing within RT departments would be beneficial.
Reference:
[1] 'Measuring and controlling emissions from polymer filament desktop 3D printers.' Prepared by the Health and Safety Executive. 2019.

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IMPLEMENTATION OF A ROBUST VMAT IMAGE GUIDED CRANIOSPINAL IRRADIATION TECHNIQUE

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Purpose: The dose at the junction of abutting sections in traditional craniospinal irradiation treatment is often associated with high levels of uncertainty. This is due to the sensitivity of the dose to the patient's position and the beam model at multiple overlapping high dose gradient regions. We report a robust, VMAT optimised 3-isocentre planning and IGRT protocol for CSI treatments, which avoids the junction problem and has been tested for patient position uncertainty.
Methods and materials: Planning templates were developed and tested on three patients previously treated with 3D-CRT techniques. The templates were based on a 3-section VMAT technique. Robustness analysis for positional uncertainty was performed using reported CBCT intra-fraction variation. Scenarios included 2mm shifts of each isocentre in 6 orthogonal directions for 3 patients. Dose parameters of relevant structures were compared for 75 plans. Plan specific QA was performed, centred on the three isocentres and the 2 junctions of adjacent regions with film and diode arrays. Only the non-shifted and worst-case shifted plans were measured. The IGRT protocol was developed based on the results of planning, robustness analysis and QA.
Results: Optimising three regions with equally spaced isocentres along the length of the cranio-spine PTV produced two automatically feathered VMAT junctions. The overlapping volumes extended ~5cm either side of the 50% isodose lines of each adjacent region. The cranial region required a full arc, and the thoracic and lumber arcs were 120°, to spare healthy tissue. For all three patients with 36 structure-parameters and 25 scenarios, tolerances were exceeded due to 2mm isocentre shifts for two scenarios and 2 structure parameters. Isocentre- and junction-centred QA passed for all non-shifted plans, and 4/6 shifted 'worst case' plans. The IGRT protocol included lumber and thoracic 'scout' 2D kV set-up verification images followed by a 3D CBCT prior to each of the 3 isocentre plan deliveries. Corrections were permitted up to 5mm in all directions for each irradiated region.
Conclusions: VMAT planning avoids sharp dose junctions between adjacent treatment regions, while easily meeting dose planning constraints. Robustness analysis has shown the VMAT plans to be insensitive to inter- and intra-fraction set-up errors, including those between isocentre deliveries. Current clinical plan specific QA protocols are more than adequate for VMAT CSI, with no special requirements for this treatment technique. Due to the robustness of the plans, a simple IGRT protocol was implemented, accounting for realistic variations in day-to-day patient treatment positions.

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PLAN ADAPTION SANITY CHECK (PASC) TOOL FOR QA AND RECORDING OF MR-LINAC ADAPTED PLANNING AND TREATMENT DATA

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Purpose: To develop an integrated software tool that provides a plan adaption sanity check (PASC) of critical treatment parameters of our MR Linac (Unity 1.5T, Elekta, Crawley UK). The tool is designed to enables users to systematically record all essential QA and other treatment information in a single database. The data is to be used for patient treatment verification, trend analysis, clinical trial data collection and improving treatment efficiency and consistency.

Material and methods: The tool was developed using a Python script (Python v3.8 and IDE Spyder v4.1.5). It combines data directly read from Mosaiq v2.81 (Elekta, Crawley UK) and the treatment planning system (TPS) Monaco v5.51 (Elekta, Crawley UK). The workflow is split into 'plan info' and 'plan data'. First, basic plan information is loaded from Mosaiq and Monaco. The Physicists/RTs begin to enter single-click time-stamp data at specific time points during treatment. Comments about the patient's position, image fusion and the plan adaption are also entered here. Once the treatment plan has been sent to Mosaiq, the data is loaded in PASC and treatment plan parameters are compared between 1) the TPS reference plan, 2) the TPS adapted plan and 3) the Mosaiq delivery plan. The parameters include all MR times and types acquired, isocentre offsets, beam monitor units, segment numbers, leaf positions and gantry angles. Time stamps may continue to be recorded throughout.

Results: All tests showed the PASC tool can easily alert the RTs to discrepancies exceeding a pre-set tolerance between the reference and the adapted beam data and ensure parameters for the adapted and delivery plans are identical. Alerts are also raised for unexpected differences in isocentre shifts and MR details. All simulated gross discrepancies were successfully highlighted for review. PASC has been used to collect treatment information from all patients treated with our Unity machine (anonymised for this report). With the tool, the efficiency for plan checks including data transfer and recording treatment information can be improved by up to 50%.

Conclusions: The PASC tool can be used to perform rapid and comprehensive validation of adapted plan delivery based on MR-guided treatment where time for QA is limited. The sanity check would also be suitable for CBCT-online plan adaption. The fast recording of QA data and other plan information in a structured database provides the department with a vast wealth of data for efficiency, dose and treatment optimisation.

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SINGLE OR MULTI COMPUTED TOMOGRAPHY SIMULATION FOR HIGH DOSE RATE BRACHYTHERAPY: IS REPLANNING NECESSARY PRIOR TO EACH FRACTION?

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Purpose: The aim of this study was the comparison, analysis and dosimetric evaluation of single versus multi computed tomography (CT) – based treatment plan for post-operative gynecological intracavitary high-dose-rate brachytherapy.

Materials and methods: Eighty (80) patients were evaluated, each of them received three fractions of 7 Gy. A CT-simulation was performed prior to each fraction. For all the CT- simulations organs at risk were delineated. The dose for 2cc and 1cc volumes for the rectum and the bladder were evaluated as well as the dose for the 100% and 90% isodose for the target. Retrospectively, for the purpose of this study, the 1st treatment plan was implemented to the 2nd and 3rd CT (revised plans). The dwell time of the first plan was corrected for the decay and applied. Then a dosimetric comparison of the results was performed. A statistical software package SPSS was used for statistical analysis.

Results: The dosimetric differences between consecutive initial and revised plans for the rectum, bladder and the target have not shown any statistically significant difference (p>0,05). However, in some cases the rectum would receive a higher total dose that exceed the acceptable dose limit if single CT was performed. This increase ranged from 0.86% to 18.75%.

Conclusions: Although the dosimetric differences were not statistically significant for organs at risk as well as for the target, the increased dose of rectum in some cases may be significant in clinical practice. Thus, the use of single or multi computed tomography simulation should be a medical/clinical decision.

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THE EVALUATION OF THE PROCEDURE OF POSITIONING DIODE IN-VIVO DOSIMETRY SYSTEM IN TATTOO-LESS BREAST RADIOTHERAPY TREATMENT

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Purpose: To evaluate the procedure of positioning diode in-vivo dosimetry system in radiotherapy tattoo-less breast treatment by comparing the measurement results between the breast treatments with and without tattoo.

Material and methods: These dose measurement were performed in field-in-field breast radiotherapy in Cancer Centre London, with half-beam blocked technique with Elekta Agility. The 55 diode dose measurements from tattoo treatment group were collected from Jun 2011 to Dec 2011 while the 63 diode dose measurements from tattoo-less treatment group were collected from Jan to Aug 2021.

The set-up position of tattoo-less patients were determined by the foot-rest positioning on the couch (Sup/Inf), the couch height (Ant/Post) and mid-line of the patient (Left/Right). Isocentre was verified by VisionRT surface-guided radiotherapy and Cone Beam Computerised Tomography (CBCT) on the first day. The diode measurement (Scanditronix EDP-15 diode) was performed on the second day of treatment with VisionRT.

The diode position was measured from medial and lateral tattoo in treatment with tattoo. With tattoo-less treatment, the diode position was measured from the laser at isocentre position (from the patient's surface). This positioning technique required a degree of treatment experience for both planning and treatment team. The treatment radiographer might find a point to put on and gave the planner the reference point measurement if they found ambiguity.

Results: The diode dose measurement readings were compared with the estimated dose from the XiO Treatment Planning System (TPS). The mean deviation were -1.01% and -0.25%, and standard deviation were 0.04, 0.03 for tattoo and tattoo-less treatment. P value for T-test is 0.1211> 0.05, with 2 tails variance which the null hypothesis is rejected. The difference between the two groups were statistically insignificant.

Conclusions: The two arms showed similar diode dose measurement discrepancies from the TPS. The diode alignment procedure without tattoo has been adopted well within the department.
As the laser systems showed on the patient's skin is different from the isocentre point on the TPS, it took longer time for training planner to find the real measurement in tattoo-less treatment than tattoo treatment. There were a longer transition period to settle in this new technique.
If the isocentre of the field fell under the couch, it will give more uncertainties on the measurement results. It would be better to implement 2D in-vivo dosimetry system for tattoo-less treatment, this will eliminate the complexity during planning and treatment.

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MONTE CARLO SIMULATION OF THE VARIAN MILLENNIUM 120-LEAF MULTILEAF COLLIMATOR IN GATE PLATFORM

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Purpose: The aim of this study was the development of the Varian Millennium 120-leaf multileaf collimator (MLC) using Monte Carlo (MC) simulation techniques. The MLC modelling accuracy was examined through comparisons with experimental measurements.
Material and methods: Based on information from the manufacturer, the Millennium 120-leaf MLC was modelled using GATE 8.2 Platform. For each leaf, tongue and groove parts, rounded end and interleaf gaps were designed based on vendor's description. Initially, for model validation, measured and calculated dose profiles arising from MLC-defined photon fields (6 MV) were compared. Measurements were acquired using an ionization chamber in water at a SSD of 100 cm, in a depth of 10 cm while the same set-up was implemented in GATE environment. Part of the verification included the determination of opposite abutting leaf leakage. Dose measurements for 6 MV photon beams were performed in PMMA slab phantom using Gafchromic films at a SSD of 95 cm, in a depth of 4.2 cm. In the first film, a reference dose distribution was delivered for a 10x10 cm2 photon field with the MLC leaves retracted. A second film was irradiated by a jaw-defined open 10x10 cm2 photon field blocked by MLC leaves which closed on central axis. The abutting leaf leakage dose was measured across leaves movement axis, under the center of an opposite leaf pair and normalized to the central axis dose of the open field to obtain dose profile. The experimental protocol was simulated using the MC algorithm.
Results: Calculated and measured dose profiles were in good agreement with an average difference of 3% for flat and penumbra region. The measured abutting leaf leakage was 26.4% and the corresponding calculated value was found to be 25.6%±1.5% resulting in a difference of 3%. Our results are consistent with literature, where the abutting leaf leakage ranges from 22% to 28%.
Conclusions: The Varian Millennium 120-leaf MLC was modelled according to the specifications of manufacturer. The performed comparisons indicate that measured and simulated data was in good agreement. Further verification is required in order to investigate whether the MC model of Millennium 120-leaf MLC can be used for independent dose verification and patient specific quality assurance tests.
Acknowledgment: This work was supported by computational time granted from the National Infrastructures for Research and Technology S.A. (GRNET) in the National HPC facility-ARIS under project ID pr010021.

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PHYSICAL VERIFICATION OF THE DOSE ENHANCEMENT BY THE PRESENCE OF GOLD NANOPARTICLES

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Purpose: A wide group of works have shown the therapeutic efficacy of radiation cancer treatment by means of radiation sensitization with gold nanoparticles (AuNPs). Beyond the expected higher radiosensitization, it would be necessary to measure the dose enhancement due to the presence of AuNPs in the initial physical process. We try to establish an experimental protocol that allows physical verification of the calculated theoretical dose in the presence of AuNPs in a clinical context, which is not still achieved, as far as we know.
Material and methods: The evaluation of clinical possibilities of AuNPs needs a more exhaustive calculation than usual. Monte Carlo (MC) was used to simulate the transport of particles interacting a material with several AuNP concentrations. An accurate experimental measurement is required to check the theoretical calculation in a new medium material composed with AuNPs. Unfortuantely, conventional devices as ionization chamber or radiochromic film interact on the nanoparticles.
A detection device, called NanoLIC, based on a liquid-filled ionization chamber was deleveloped, adapted for the experimental measurement of the dose in the presence of AuNPs by filling the cavity with liquid isooctane and dodecanethiol, which are both non-polar and hydrophobic mediums. This liquid was also composed by special preparation of 5nm AuNPs. A specific phantom was also designed for the hosting of the liquid chamber.
Considering the more suitable energy spectra, the beam modality used to combine with nanoparticles was MV photon beams from Megavoltage Cone Beam Imaging system of a Siemens Oncor linac, as a proof of concept of a beam with energy low enough to enhance the effect of the AuNPs.
The performed experimental measurements were simulated by MC calculation with the codes EGSnrc, BEAMnrc, and DOSXYZnrc and explicit modelization of the NanoLIC was performed with egs_chamber user code.
Results: The measurements made with the AuNPs dosimetric verification system showed agreement with the values obtained through the MC simulation.
Conclusion: The developed verification system can be used for assess the dose enhancement due to the presence of AuNPs. The theoretical MC calculation was supported by the experimental measurement, so it provide us confidence about the in silico results within a sequential runnning project for evaluating the clinical implementation of AuNP in radiotherapy routine.

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A NEW TPS FOR ELECTRONIC BRACHYTHERAPY CALCULATION: VALIDATION TESTS FOR GYNECOLOGICAL IMPLANTS

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Purpose: The treatment planning system (TPS) BrachyCare (Tecnicas Radiofisicas S.L.) is a new software that has been developed for planning the treatments performed with Xoft Axxent electronic brachytherapy (eBT) system, supporting additionally the use of isotope brachytherapy sources. The aim of this work is to compare the dose calculation results in gynecological clinical plans obtained with the new system to the results obtained using an existing TPS.
Material and methods: 30 gynecological brachytherapy clinical plans already treated with Ir-192 (GammamedPlusiX, Varian Medical Systems) and planned with BrachyVision (Varian Medical Systems) at Hospital A, were calculated retrospectively with BrachyCare with the Ir-192 source. The applicators used were the vaginal cylinders (10 plans), intrauterine probes (10 plans) and Fletcher applicator (10 plans).
20 gynecological brachytherapy clinical plans already treated with Axxent eBT source and BrachyVision at Hospital B, were calculated retrospectively with BrachyCare with the Axxent eBT source. The applicators used were the vaginal cylinders (10 plans), and tandem applicators (10 plans).
Dwell times and dose prescription were the same for each Ir-192 and Axxent eBT plan in BrachyCare and BrachyVision. In both systems was used the TG-43 approach for the calculation.
The results have been evaluated by comparing the dose calculated at 5 different reference points (% local dose difference) for each plan, and by performing 3D gamma analysis (passing rate 2mm/2%), using the Verisoft software (PTW) with the 3D dose matrix exported from all the plans and from each TPS. For the gamma analysis, the 100% dose was set at the total prescription plan dose.
Results: For the Hospital A plans, the mean deviation at the dose points evaluated was 0.5% and the standard deviation was 0.7%. The maximum deviation was 2.3%. The passing rate for the gamma 3D matrix evaluation was 99.3% in average, being the lowest value 97.6% For the Hospital B plans, the mean deviation at the dose points evaluated was -0.4% and the standard deviation was 0.6%. The maximum deviation was -2%. The passing rate for the gamma 3D matrix evaluation was 99.2% in average, being the lowest value 97.8%.
Conclusion: The new BrachyCare TPS is validated in gynecological implants and the calculation of the Axxent eBT source in BrachyCare is clinically equivalent to BrachyVision.

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DOSE PERTURBATION CALCULATION OF ELECTRON BEAM INCIDENT ON SKIN TATTOO USING PHITS

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Purpose: Electron beam therapy has been widely used to treat skin cancers and superficial tumors. This technique results in dose perturbation as the electron encounters an interface like high-Z materials. Tattooing is both a cultural and social phenomena, making a significant number of the adult population have tattoos. The typical black tattoo ink used is mostly composed of high-Z materials like Iron. However, limited studies were made on the dosimetric effects of electron beam on tattoo. Thus, this study numerically investigated the dosimetric effect of tattoo on skin at chest area when exposed to electron beam irradiation using the Particle and Heavy Ion Transport code system (PHITS).
Methods: Electron beam interaction on skin interface with and without tattoo was numerically investigated using a Monte Carlo particle transport code PHITS and the male ICRP Reference Computational Phantom. For the tattooed phantoms, the tattoo was inserted in the dermis, and was represented by a cylinder of height 0.08 cm with 0.3 cm radius. The phantom was set at 100 cm away from a 20 MeV electron beam source. The density and chemical composition of the tattoo were taken into account to calculate surface dose perturbation using T-deposit tally card.
Results: Dose perturbation (DP) is calculated as the ratio of dose with and without tattoo. Based on the male phantom simulation with an electron beam, the rendered DP was 1.17. This value is found consistent with the experimental trends conducted by previous studies. The calculated DP showed that the presence of ink caused an increase in the dose deposited on the dermis layer which warrants consideration as to radiation therapy implementation.
Conclusion: The presence of tattoo on skin rendered an increase in the dose deposited by the incident electron beam. Though this is a preliminary study, numerical investigation of dosimetric effect of electron beam irradiation on skin with tattoo with other dependencies of DP must be explored to appropriate radiation treatment plans.

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ENHANCED ACCURACY IN MR-BASED 3D POLYMER GEL DOSIMETRY FOR END-TO-END TESTING IN MULTI-TARGET SRS APPLICATIONS

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Purpose: Polymer gel dosimetry using MRI read-out can provide 3D treatment plan verification, an important procedure for stereotactic radiosurgery (SRS) applications. During MRI read-out, potential B1 inhomogeneities may compromise the method's dosimetric accuracy, especially if multiple targets are involved, i.e., discrepancies in flip angle excitation may bias the obtained results. This work proposes an end-to-end quality assurance (QA) workflow, which comprises B1 inhomogeneity correction and enables globally normalized relative dosimetry in multiple brain metastases SRS cases.
Material and methods: Two identical, 3D-printed, anthropomorphic head phantoms were filled with a 3D polymer gel dosimeter and underwent a CT scan, following the clinical SRS workflow. A treatment plan of eleven small lesions (distributed over the entire brain parenchyma) was prepared and delivered to the first phantom. Target prescribed doses varied between 18 and 24 Gy. Both phantoms were scanned at 1.5T approximately 24 hours post-irradiation using multiple pulse sequences to implement flip angle, as well as R2 (transverse relaxation rate), mapping. MRIs of the second (unirradiated) phantom were used to determine the 3D distribution of B1-induced background R2 bias. Acquired R2 variation maps were deducted from corresponding R2 maps of the irradiated phantom, yielding a 3D R2-matrix corrected for B1 inhomogeneities. Dose distributions without B1 correction were also obtained. Measured and calculated dose distributions were globally normalized to the center of a target located close to the scanner isocenter. All distributions were interpolated to the TPS-calculated dose matrix dimensions for reference purposes.
Results: Globally normalized dose measurements without correction were found to deviate by more than 20% in lesions lying in the periphery of the imaged volume, although deviation from unbiased R2 values decreases substantially close to the isocenter. B1 inhomogeneity correction considerably improved (up to 15%) the level of agreement between measured and calculated dose profiles in most targets. 3D global gamma index passing rates (5%/2mm) were 77% and 92% for the uncorrected and corrected distributions, respectively. The proposed methodology does not suffer by B1

inhomogeneity enhancement observed in vivo due to dielectrical property differences between tissues and only slightly affects overall image quality.
Conclusion: B1 inhomogeneity may considerably bias gel measurements in multi-target dosimetry. Although the proposed workflow involves several image processing steps and requires expertise in polymer gel dosimetry, it improves the dosimetric accuracy in globally normalized multi-target 3D dose measurements. This work contributes towards the wider adoption of 3D dosimetry in end-to-end QA for SRS applications.

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MODEL-BASED COMPARISON BETWEEN DEEP INSPIRATION BREATH HOLD AND FREE BREATHING TECHNIQUES IN LEFT-SIDED BREAST CANCER PATIENTS

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Purpose: Postoperative radiation therapy (RT) for left-sided breast cancer patients may be cause of heart toxicity. Deep inspiration breath hold (DIBH) technique reduces cardiac radiation exposure. The aim of this study is to apply normal tissue complication probability (NTCP) models to quantitatively compare DIBH and free breathing (FB) techniques, analyzing dose distribution in lung, heart and its substructures, in particular coronary arteries.
Materials and methods: Twenty-five consecutive left-sided breast cancer patients having undergone conserving surgery and breast RT were selected from our clinical database. Planning CTs were acquired in both FB and DIBH modalities. Cardiac chambers and coronary arteries were delineated according to ESTRO guidelines. For each patient, FB and DIBH plans were simulated to be equivalent for target coverage, namely 95% prescription dose (40 Gy in 15 fractions on whole breast plus 10 Gy in four fractions on tumor bed, when appropriate) to 95% of target volume. Dosimetric parameters for the heart, cardiac substructures and left-lung were retrieved and compared between DIBH and FB simulation plans. Three Lyman Kutcher Burman (LKB) models were applied to evaluate perfusion defects (Das et al, 2005), long-term cardiac mortality (Gagliardi et al., 1996), radiation-induced pneumonitis (Rancati et al., 2013) in both techniques. The relative risk (RR) was evaluated as RR = (NTCP DIBH/ NTCP FB).
Results: Whole heart and coronary arteries doses were significantly reduced in DIBH plans considering all dosimetric parameters. In particular, the heart mean dose (Dmean) and the heart maximum dose (Dmax) were reduced in DIBH approach by 37% and 59% respectively. All cardiac chambers reported a significant dose reduction in Dmean and near-maximum D2%. Left-lung dosimetric evaluation reported a significant reduction of Dmean ($p=0.001$) and of lung volume receiving at least 20 Gy (V20Gy) ($p=0.003$). The NTCP estimations showed a RR<1 considering perfusion defects and long-term cardiac mortality and a significative reduction of radiation-induced pneumonitis in DIBH plans ($p<0.0001$). However, in 5 patients a higher risk of pneumonitis complication with DIBH techniques was observed, probably associated to a larger lung volume involvement.
Conclusions: The dosimetric benefit of DIBH over FB therapy was consistently observed for all cardiac substructures and left-lung. The DIBH technique promises a significant advantage in ameliorating the heart toxicity profile of left breast irradiation.

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IMRT VS. 3DCRT VS. HYBRID | A COMPARATIVE STUDY IN BREAST CANCER PATIENTS

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Purpose: There are different approaches to employ radiotherapy for conservative breast cancer. The purpose of this work was to analyze and compare dosimetric parameters of treatment plans calculated using three delivery techniques; Conformal Radiotherapy (3DCRT), Intensity Modulated Radiotherapy (IMRT), and a hybrid technique (HT), currently under development.
Material and methods: 3DCRT and IMRT treatment plans for 30 left-sided (LS) and 27 right-sided (RS) breast cancer patients were calculated. An approach to a HT was made for 6 of those LS patients. A dose of 50 Gy in 25 fractions to the Planning Target Volume (PTV) was prescribed. A thorough statistical analysis was performed using Python scripts, in order to assess the impact of each technique on the plan namely PTV coverage and dose homogeneity, and dose to critical organs at risk.
Results: Regarding the PTV, IMRT provided slightly lower mean dose for LS patients. The maximum dose was inferior with IMRT for LS but similar for both techniques in RS. IMRT accomplished higher minimum dose and better D2%.
For the heart, IMRT delivered higher mean dose for both sides but lower maximum dose for LS. V30Gy difference was not significant, in contrast with V20Gy (larger for IMRT); for RS these yielded null values.
For both ipsilateral lungs, IMRT resulted in higher mean dose, smaller V30Gy and larger V10Gy. V20Gy was inconclusive.
IMRT unequivocally delivers better conformity and homogeneity.
Regarding the 3DCRT/IMRT/HT analysis, none of the dosimetric parameters for the PTV showed significant differences. Conformity was worse with hybrid and 3DCRT and homogeneity showed no statistical divergences.
Conclusions: IMRT indeed provides better target coverage, retaining the dose delivery to desired levels of homogeneity and conformity; also, considerable hotspots present when 3DCRT is applied disappear with IMRT. IMRT has shown to be more conservative in terms of high doses to organs at risk, but results in wider low-dose regions and higher mean dose. Analogous conclusions can be taken for the ipsilateral lung and the volume comprising both lungs.
Considering the HT, it was not possible to draw conclusions for the PTV. CI* and HI** were still superior with IMRT but improving the sample size could yield better results for the HT and encourage its implementation (adding to the benefit of lowering the MU in comparison with IMRT).
* Conformity Index = $(V95\%[PTV])^2/(PTV \times V95\%[Total])$
** Homogeneity Index = (D2% - D98%)/D50%

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COMMISSIONING OF A 4DCT SCANNING PROCEDURE

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Purpose: The use of 4DCT imaging is considered as a minimum requirement for the implementation of stereotactic ablative radiotherapy for patients with early-stage non-small cell lung cancer. This study focuses on evaluating the accuracy of the Vision RT SimRT surface tracking system as part of its commissioning process and assessing the achievable accuracy for 4DCT reconstruction prior to clinical use at University Hospital Galway.

Material and methods: Helical 4DCT imaging was performed using the Canon Aquilion LB CT scanner. Breathing and lung target motions were simulated with the CIRS Dynamic Thorax Phantom Model 008A. Communication between the SimRT system and the CT software was tested and the validity of the recommended pitch factors for each input breath rate was then investigated. Experiments were then performed to assess the tracking accuracy SimRT by comparing recorded waveforms with the input data using the Pearson's correlation coefficient. To determine the achievable accuracy with the 4DCT system for lung imaging, 3D- and 4D-CT images of the CIRS phantom were acquired with 1 cm and 3 cm diameter target spheres using the departmental imaging protocols. 4DCT images were reconstructed using phase-based binning methods. Positional and volumetric imaging accuracy was then analysed in Monaco TPS version 5.51 at different respiratory phases including 0%, 50%, mid-ventilation phase.

Results: Communication between SimRT and Canon CT was verified through accurate identification of breath rates. The recommended pitch factors from the Canon CT software were found to be valid for use with baseline drifts of ≤ 0.3 mm determined from the tracked waveforms. Tracking accuracy tests revealed limitations in accurate determination of the absolute magnitude of motion when tracking surfaces on inclined planes but was found to have no effect on the reconstructed 4D scans. The SimRT demonstrated high dynamic tracking accuracy with PCC values > 0.99 obtained. From the 4D scans, average volume deviations found for the 3 cm target sphere were 2.8%, 3.3% and 4% at the 0%, 50% and mid-ventilation phases, respectively. For the 1 cm sphere, average volume deviations were 4.3%, 5.3% and 6.4%, respectively.

Conclusion: The study performed provided a framework for commissioning of the surface guided system for 4DCT imaging with the Canon Aquilion LB scanner. The SimRT system showed to be a robust tracking system for phase-based binning of images. From this study, the most accurate phase for target delineation was found to be the inhalation (0%) phase.

ABSTRACTS – DIY FAIR

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PYTHON TREATMENT PLANNING SYSTEM FOR EGSNRC MONTE CARLO SIMULATIONS

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Monte Carlo (MC) simulations in radiotherapy research are commonly performed using Electron Gamma Shower (EGSnrc) package. A method of using EGSnrc to calculate dose in orthovoltage treatments was developed. Patient CT based phantoms can be created with EGSnrc 'ctcreate' code. The simulations are then set up by appropriate orientation of a Phase Space (PHSP) file (containing all particle data coming from the accelerator) in spherical polar coordinates relative to the phantom. Limitations of this approach include the lack of visualization of the setup, regular voxel spacing and voxel material assignment. The objective of this work was to overcome these limitations through the development of web-browser based applications using Python packages 'Plotly' and 'Dash'.

The first application, 'OrthoPlan', provides a logical workflow to set up the MC simulations. Orthovoltage treatments often require custom made lead cutouts to shape the radiation beam. These cannot be CT scanned to be included in the simulation phantom due to CT artefacts. OrthoPlan allows the user to import a DICOM structure set and overwrite the HU values of voxels contained inside a structure, hence creating a lead cutout without artefact.

Adaptive voxel grid creation feature of OrthoPlan allows the user to select three regions: a region of interest with high resolution voxels, a region of dose spread with lower resolution voxels and a region to be disregarded for the simulation. This process minimizes the number of voxels to optimize the simulation time while maintaining the relevant phantom volumes.

OrthoPlan can create a phantom file of a new format based on an extended tissue library to allow accurate tissue segmentation, which is of importance in orthovoltage simulations. EGSnrc code was altered to accommodate this new phantom file format.

Coordinates defining the orientation of the PSHP file in the simulation input file can be determined via 3D interactive planning in OrthoPlan.

The second application, 'OrthoDose', facilitates with dose normalization to a point and consequent conversion of 3D dose file to a DICOM format that can be uploaded to a commercial TPS. It also provides the tools to calculate and examine Dose-Volume metrics as in routine clinical practice.

These user friendly Python applications, with a modern aesthetic, allow physicists with no prior MC experience to set-up and analyze EGSnrc simulations which is of major importance in introduction of routine orthovoltage treatment simulations in the department as part of ongoing PhD research.

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MEDICAL IMAGING TEACHING AND TEST LABORATORY (MITTLAB)

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Introduction: University of Oulu and Oulu University of Applied Sciences have established a Medical imaging teaching and test laboratory (Mittlab) in a two year (2021-2022) European Regional Development Fund -project. The laboratory is dedicated to teaching, research, development, innovation and testing activities by providing a single infrastructure that serves the needs of research, education and companies in a versatile manner. Even though laboratory is located in the Oulu University Hospital in Finland, it can be partly accessed from anywhere from the world, as the virtual elements will be freely available for stakeholders worldwide.

Overview: Mittlab offers a wide selection of physical and virtual tools to simulate, test and train the use of different medical imaging devices. Virtual components of the laboratory include 360°-virtual

simulation environments of imaging suites and virtualized imaging device interfaces (MRI, CT and radiography). Novel 360° -virtual environments are based on spherical panoramic images and 360° technology. They include added learning material in text, images and video formats, and can be accessed via any smart device with a network connection with no need of special applications. Virtually implemented medical imaging devices (CT, MRI, radiography) enable learning of the device operation and physics behind it independent of time and place. They have low hardware requirements, and they can be accessed with a network connection with free applications that are provided on the laboratory webpages.

Physical imaging equipment of the laboratory include a radiography, mammography, cone-beam CT system and conventional CT system, of which some are purchased and some donated by Oulu University Hospital. In addition, laboratory have acquired a set of phantoms and radiation measurement devices that are available for its users.

The laboratory's physical and virtual equipment can be used to improve education in biomedical engineering, medical physics, radiation protection and in the training of radiographers and nurses. Laboratory also offers an opportunity for research institutes and companies to advance their research and products by allowing testing in facilities similar to a hospital environment. This can help the commercialization of products and prototypes.

Conclusions: The established laboratory aims to respond to the needs of universities and medical industry partners from educational, research and development perspectives. It offers a wide selection of virtualized simulation tools as well as physical imaging equipment that can be used to improve education and to advance research and product development.

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DEVELOPMENT OF A NOVEL STEREOLITHOGRAPHY 3-D PRINTED AORTIC PHANTOM FOR THE ACCURATE QUANTIFICATION OF 18F-FLUORODEOXYGLUCOSE UPTAKE IN AORTA ATHEROSCLEROTIC INFLAMMATION

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Purpose: In recent years, 18F-FDG positron emission tomography (PET) imaging has emerged as a novel means to image vascular wall inflammation that is associated with early stage atherosclerosis and plaque rupture. At-present there is no recommended standardized quantitative parameter or protocols for imaging atherosclerosis with PET.

The use of PET imaging phantoms has been well established and well documented for oncological studies. However, there are currently no available phantoms specifically designed for simulating atherosclerotic radiopharmaceutical distributions and having the structures and dimensions similar to that of an inflamed arterial vessel. This research aimed to design and construct a 3D–printed aortic phantom closely replicating the basic dimensions, structural features and activity distribution of an inflamed atherosclerotic aorta, to facilitate PET imaging investigations of atherosclerosis.

Materials and methods: A long cylindrical model containing another cylinder was proposed with two fillable voids, replicating the vessel wall and lumen of the aorta with clinically relevant vessel wall diameters (approx. 1.5–4 mm). Separated voids were proposed to allow for the clinically relevant uptake ratios within the phantom (3:1 vessel wall to blood ratio). Two manufacturing techniques were carried out at UCD I-Form Advanced Manufacturing Research Centre for constructing the phantoms. Fused deposition modelling (FDM) 3-D printing and stereolithography (SLA) 3-D printing approaches were employed. It was essential for the phantom to be watertight at all phantom boundaries to avoid radiopharmaceutical leakage and to ensure uptake ratios between the simulated vascular wall and lumen space were maintained. It was important for the phantom to be easily fillable, for radiation protection purposes. Inlets and outlets containing taps were proposed for the final design. The Hounsfield Units (HU) of the phantoms were analysed using CT imaging.

Results: The FDM PLA phantoms were found to not be watertight leading to radiation protection and uptake ratio issues. The SLA approach yielded watertight resin phantoms. SLA involves the curing of liquid resins using a UV light source which produces a more watertight print. The phantoms were easily fillable with liquid 18F and underwent multiple PET/CT scans in a water phantom facilitating investigations for the characterisation of PET/CT reconstruction techniques for the accurate quantification of 18F-FDG uptake in sub 5 mm inflammatory atherosclerotic lesions.

Conclusion: For the first time, a PET phantom model of the aorta was created using a SLA 3D printed approach, simulating inflammatory-like lesions used for investigations into optimum PET imaging of atherosclerosis.

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A WEB-APPLICATION PLATFORM FOR IMAGE QUALITY TESTING

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The use of in-house developed code and programs for quantitative image quality assessment has become more widespread in diagnostic radiology. However, these software solutions are not always accessible; requiring either licensed software or if open source, a specific collection of packages and libraries. This can lead to working solutions becoming unusable or lost if a staff member leaves, requiring a lot of duplicate effort to recreate code to maintain the same standard of QA in the department.

The aim of this project was to utilize Flask, a micro web framework built in Python to deploy QA programs as a Web-App. The advantages of this are many; software and hardware requirements are reduced. A user only requires an internet connection (or intranet, depending on host location) and a web browser - it can even be accessed by a mobile phone. Centralizing the codebase ensures that all of the department are using the same, latest revision of software ensuring result parity when testing.

Centralization of the software also has an additional benefit in allowing easy, automatic data collection opening up the possibility of in depth trending and statistical analysis of key image quality metrics for specific systems or across entire modalities.

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A CUSTOM 3D PRINTED SOLUTION FOR AFFIXING ADDITIONAL FILTRATION TO AN X-RAY TUBE

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The goal of this project was to design a tool that would aid in attaching additional metal filters (copper, aluminium or a combination thereof) to the x-ray tube of various different units. There were significant design challenges for this project that needed to be overcome. An ideal solution needed to fit a variety of different filter sizes, thicknesses and even a combination of filters. The device must also be usable on a variety of different tube head designs. The device should be easy and quick to use, allowing for rapid removal of filters to check light-beam alignment or positioning.

Owing to these niche, specific requirements it was determined that a custom solution was required. A prototype design was created in CAD (computer assisted design) and 3D printed. While initial costs are high, this can be alleviated if a department has their own 3D printer.
When compared to the current solution of affixing filters directly to the tube with tape, this device is indefinitely reusable, doesn't leave sticky residue on the system and is outside the beam and so does not interfere with uniform exposures. There is also a reduced chance in the filters falling mid-test, interrupting QA and potentially damaging the detector due to loss of adhesion from the tape.

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OPEN-SOURCE SOFTWARE FOR AUTOMATED ULTRASOUND IN-AIR IMAGE QUALITY CONTROL

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Ultrasound (US) examination is the most common imaging examination due to its ease and speed. The diagnostic quality of the US image may be impaired, for example, if the transducer's piezoelectric crystals break. Therefore, regular evaluation and monitoring of the US image quality is important. The US image quality assessment practices vary from manual reviewing to detailed assessment using commercial or custom software solutions. The purpose of this project was to develop open-source software for an automated ultrasound transducer quality assessment from in-air reverberation patterns with an aim to partially automatize US quality assessment.
In a previous study by Horssen et al. 2017 (DOI: 10.1177/1742271X17733145) an automated US image quality framework was developed that analyses the reverberation patterns from the transducer's air scan images. The horizontal and vertical profiles determined from reverberation regions are detected and analyzed. Our open-source software solution performs a similar analysis as presented in Horssen et al. 2017. First, the software performs an automated analysis using the air reverberation US image, and the analysis results are stored as a python dictionary in a dedicated folder structure based on DICOM metadata information on the analysis server. Once this analysis program is started, it monitors to a directory and automatically performs the analysis on the US images in the background. After the analysis, the user can assess and view the results web browser-based visualization program for monitoring and trend follow-up. A log file highlighting transducers that are impaired based on analysis is also updated. The analysis and visualization programs are Python-based, and the visualization program is built with Flask micro-framework. For this work, we evaluated the software performance using a small set of US images from three different ultrasound system vendors.
The open-source software is available for download at https://github.com/MIPT-Oulu/Ultrasound_IQ_analysis. For the test set US images, the program was able to automatically analyze all images, and the user assessment of analysis outcome was easy using the web browser solution.
The software enhances and optimizes US image assessment over manual reviewing. However, a more detailed assessment has to be performed in future studies to assess the suitability of the analysis parameters in the trend follow-up. Our future aim is to extend this software also for open-source automated quality assurance to other imaging modalities.

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COMPUTED TOMOGRAPHY SIMULATOR (CTLAB)

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University of Oulu and Oulu University of Applied Sciences have established a unique medical imaging teaching and testing laboratory in collaboration with Oulu University Hospital in a European Regional Development Fund -project. Virtually implemented medical imaging devices (CT, MRI, radiography) are unique features of the lab. Many of the virtual tools have been developed by the universities themselves. One of the virtual tools implemented during the project is the CTlab simulator, which can be widely used in computed tomography training for all professionals who use radiation in their work. The CTlab provides fast, comprehensive, and efficient solutions for numerical CT simulations with low hardware requirements. The simulator has been developed to introduce the basic operations and workflow behind the CT imaging modality and to illustrate how the polychromatic x-ray spectrum, various imaging parameters, scan geometry and CT reconstruction algorithm affect the quality of the detected images. Key user groups for the simulator include medical physics, engineering, and radiographer students.
CTlab has been created with MATLAB's app designer feature. It offers its user the opportunity to select the virtual imaging target, to adjust CT imaging parameters (image volume, scan angles, detector element size and detector width, noise, algorithm/geometry specific parameters), to select specific scan geometry, to observe projection data from selected imaging target with polychromatic x-ray spectrum, and to select the specific algorithm for image reconstruction (FBP, least squares, Tikhonov regularization).
The CTlab has so far been used at a postgraduate course on computed tomography technology with encouraging feedback from the students. At the course, teaching of CT modality were performed by using the simulator, giving students unlimited opportunity to practice the use of virtual imaging device and participate demonstrations remotely during the Covid-19 pandemic. Using CTlab in teaching enhances and deepens the learning experience in the physics behind computed tomography.
CTlab can be used remotely (https://www.oulu.fi/fi/projektit/laaketieteellisen-kuvantamisen-opetus-ja-testilaboratorio-0), which makes teaching and training of CT scanner usage successful regardless of time and place. The simulator enables more illustrative and in-depth teaching and offers cost-effectiveness, versatility, and flexibility in education. CTlab can also be used to support teaching in special situations, such as during the Covid-19 pandemic when simulator is utilized remotely to perform teaching-related demonstrations flexibly and safely.

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INNOVATIVE LOW CONTRAST DETECTABILITY PHANTOM AND DEDICATED SOFTWARE

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The assessment of low contrast detectability (LCD) is an important part of any quality control (QC) program in digital radiology. It generally involves the evaluation of threshold contrast (Cth) for inserts of various dimensions, appropriately located in dedicated QC test tools. Our idea is to apply a simplified method, based on a statistical model approach, suitable for different modalities in digital radiology.

The statistical method (SM) applied in this work was first presented and described in detail by Chao et al. (A Statistical Method of Defining Low Contrast Detectability, Radiol. Soc. North Am., 2000).

Considering several identical regions of interest (ROI) placed on a uniform background, the Cth characterised by a 95% confidence level is given by:

$Cth(x)=3.29\ \sigma\mu(x)$

where $\sigma\mu$ is the standard deviation of all means from ROIs of the same size as the insert under consideration.

A dedicated phantom was designed to apply the outlined method in different modalities.

It consists of:

- An acetate sheet.
- A central uniform aluminium insert (4x4cm^2, 0.5mm thick).
- An aluminium step wedge, from 0.25 to 1.25 mm. The size of each step is 0.8x0.8cm^2.
- A laterally displaced lead insert (1x1cm^2, 2mm thick).

The LCD assessment is carried out on the uniform central image area in terms of PV difference. The aluminium step wedge is necessary for image calibration, to convert from PV into millimetres of aluminium (mm Al).

Evaluation of the SM test object images was performed with an on purpose developed Matlab® code. The Software, after the identification of the position and the orientation of the phantom, placed the main ROI (typically 120x120 pixels) over the central uniform region and a series of ROIs over the aluminium step wedge. The software automatically evaluates the Cth and estimates the conversion factor between pixel value to Al thickness. Raw results of the analysis were also processed with a 3rd -order fitting and eventually interpolated over the detail size of commercial phantoms (e.g., CDMAM).

Finally, Cths are evaluated from the software in terms of pixel value units (PV) percentage contrast (C%) and millimetres of Al (mmAl).

A final report with the Cth of every single image is saved for further analysis.

This phantom and the dedicated software have been already applied over different modalities, from mammography to fluoroscopy or DSA.

Results have been published in different papers together with a comparison with already widely adopted methods and phantoms.

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AUTOMATIC TUBE CURRENT MODULATION QA TEST IN CT: PHANTOM SCAN, ANALYSIS, AND CODE - PLAIN AND SIMPLE

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Introduction: Tube current modulation (TCM) aims to achieve constant image quality in computed tomography (CT) slices by adapting the X-ray tube current as a function of patient attenuation. Constancy of TCM is important and should be evaluated with quality assurance (QA) measurements. In this work, we describe a fast TCM QA protocol using CT dose phantom.

Phantom set-up: A 16-cm diameter CT dosimetry phantom was mounted on the head support extension of the patient table. A 32-cm CT dosimetry phantom was positioned next to the 16-cm phantom on the patient table on its side, such that the circular symmetry was along the coronal plane. Scan isocenter was fixed to the middle of the 32-cm phantom. Positioning the phantoms this way provided a constant attenuation target offset from the isocenter, an instantaneous change in attenuation at the boundary of the two phantoms, and a continuously changing attenuation profile.

Imaging protocol: Example scan was performed with the Revolution EVO CT scanner (GE Healthcare, Chicago, IL, USA). A posteroanterior topogram was acquired before a helical CT scan (120 kV, 0.625 mm slice thickness, 0.9844 pitch, 0.5 s rotation time, standard FBP kernel). The scan range covered both phantoms and roughly 10 cm of additional volume in both superior and inferior directions. Full range of mA values [10 mA, 540 mA] was allowed for TCM to prevent saturation in areas of low and high attenuation, and the noise index was set to 35.

Analysis code: Average mA and slice position were extracted from the DICOM header of each cross-sectional image of the scan to obtain the mA-profile along scan length using a Python (v. 3.10) script. Consecutive QA scans could then be compared to this baseline scan visually and numerically. In this shareable code we concentrated on the most relevant TCM parameter, which is the tube current, as we wanted to keep the workflow as simple and quick as possible. Image quality analysis including noise evaluation is an obvious extension to be added to our implementation in the future.

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SCRIPTING IN ECLIPSE (ESAPI)

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Radiotherapy planning is nowadays supported by advanced treatment planning systems (TPS). Most of the functionalities required for the clinical routine are implemented in commercial software and promptly available to the final user. However, some specific needs my not be covered and some TPS offer the possibility to integrate the commercial features with in-house developed software. This is the case for the Varian TPS Eclipse. In this DIY demonstration we will present how to code a simple script from a blank project. The platform we will use is based on the Eclipse Scripting API (ESAPI) libraries, freely available upon request. The user can implement the in-house developed code in a non-compiled script executed by Eclipse, in a compiled plug-in script or in a standalone executable. The increasing complexity of the implementation provides increasing flexibility and the choice depends on the purpose of the project. Potential applications can extend from automated planning to data extraction and analysis. During this DIY demonstration we will code a simple script to extract some parameters from a treatment plan. This will show how to access parameters such as gantry angle, jaw position, control points and delivered MUs. In particular, we will extract the overall distance travelled by the MLC leafs during the delivery of a volumetric modulated arc therapy (VMAT) plan. Potential applications of such script include for example the reduction of patient specific quality assurance. The DIY demonstration will conclude with the reference to training material and more advanced repositories.

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PRIMO WATCHDOG: A SET OF PYTHON SCRIPTS TO AUTOMATE THE SIMULATIONS OF IMRT AND VMAT PLANS WITH THE PRIMO MONTE CARLO SOFTWARE

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The PRIMO Monte Carlo software [Strahlenther Onkol. 2013;189:881-886] allows the simulation of clinical IMRT and VMAT plans for Varian linacs. PRIMO relies on the general-purpose Monte Carlo code PENELOPE and the fast Monte Carlo code DPM.

The setup of a plan simulation in PRIMO takes 5-10 min, as several manual steps are needed: project creation, selection of phase-space file, import of DICOM files, selection of simulation parameters, etc. A manual import of the dose file from the treatment planning system (TPS) is also needed to compare PRIMO and TPS dose distributions. PRIMO includes an advanced macro mode to speed up the process, but the macro file creation is also manual. Hence, the simulation of plans on a routine basis can be very time-consuming.

We present PRIMO WatchDog, a set of scripts written in Python 3.7 that automate the simulation setup process. Briefly:

- The scripts run in background monitoring a specified folder. Plan DICOM files can be pasted in this folder or exported from the TPS.
- When the DICOM files are detected, the patient and plan ID, linac ID, beam energy, and MLC model, among other parameters, are read from the DICOM files.
- From the plan data, the scripts create a PRIMO macro file to setup the simulation and the gamma analyses.
- The scripts start PRIMO with the macro file, and the simulation begins.
- Once the simulation and the gamma index analyses are done, the scripts store the results in a CSV text file for further analysis. Then, PRIMO is closed and the scripts are ready to process a new simulation.

The software was tested with the following hardware and software:

- PRIMO v. 0.3.1.1816 with Windows 7 and Windows 10 operating systems.
- Varian phase-space files for 6 MV and 6 MV FFF photon beams.
- IMRT and VMAT plans from Varian Eclipse 15.6/16 for TrueBeam linacs with Millennium 120 and HD MLC models.
- The scripts were compiled to a Windows executable file with PyInstaller 4.10 (https://pyinstaller.readthedocs.io/).

More than 200 clinical plans have been simulated up to date with the help of PRIMO WatchDog.

In summary, the PRIMO Watchdog scripts automate the simulation setup and data collection for Monte Carlo simulations of clinical IMRT and VMAT plans with the PRIMO software, with a minimal workload for the medical physicist. This facilitates introducing PRIMO as a system for independent calculation in the clinical workflow.

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AUTOMATIC DATA GATHERING FROM RADIOSURGERY PLANS CREATED WITH THE BRAINLAB ELEMENTS CRANIAL SRS AND ELEMENTS MULTIPLE BRAIN METASTASES TREATMENT PLANNING SYSTEMS

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The Brainlab radiosurgery treatment planning systems Elements Cranial SRS and Elements Multiple Brain Metastases (MBM) generate many dosimetric data of interest for each plan. These data are available in the Treatment Parameters PDF reports provided by the systems. Although it is possible to manually gather such data to create a plan database, the process would be time-consuming and error-prone.

We present the Elements Data Gatherer, a set of Python 3.7 scripts to extract treatment plan data from the PDF plan reports generated by the Elements Cranial SRS 1.5 and 3.0, and by the Elements MBM 3.0.

The scripts can analyze multiple PDF reports sequentially, with the help of the Python packages slate3k (https://pypi.org/project/slate3k/) to parse text, and tabula-py (https://pypi.org/project/tabula-py/) to parse tables. The extracted data are stored in a text file in CSV format to facilitate further analysis.

Data gathered for each plan include prescription data (number of PTVs treated, PTV name, prescribed doses, prescription isodose line, number of fractions, desired coverage volume and dose, PTV size and volume), PTV dose data (mininimum, mean and maximum doses), inverse Paddick conformity index, Paddick gradient index, local brain VxGy), OAR data (name, volume, minimum, mean, and maximum doses), beam and machine data, and arc data (gantry, collimator, and couch angles, and MU per arc).

The scripts may be compiled into a Windows executable file with PyInstaller 4.10 (https://pyinstaller.readthedocs.io/) to be used in a computer without a Python environment available. The only requirement is to have installed the Java Runtime Environment, which is freely available from https://www.java.com/. In the current version 2.05 the scripts successfully extracted data from reports of about 40 Cranial SRS plans, and of 5 MBM plans.

In summary, a set of Python scripts were developed to automatically extract plan data from the PDF reports created by the Elements Cranial SRS and Elements Multiple Brain Metastases treatment planning systems.

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THE QUALITY OF A DOSIMETRY: QUANTIFYING IT, MONITORING IT AND IMPROVING IT WITH OUR QUALITY INDEX, A PSEUDO TUMOR CONTROL PROBABILITY WITHOUT COMPLICATIONS

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The ideal dosimetry treatment would deliver 100% of the prescribed dose to the tumor, and 0% to the organs at risk (OAR). We tend to this top-quality utopia when instrumentation, techniques, location of the tumor and patient's anatomy, among other things, work together in our favor. The reality is that an objective assessment of the quality of a dosimetry involves different definitions of quality for different situations, due to the lack of a direct and absolute way to state that a dosimetry has a good quality.

In our service we have established a way of evaluating the quality of a dosimetry by comparison with a reference established from a set of analogue dosimetries (same pathology, technique and equipment, etc.) already carried out, and clinically approved.

With a significant number of dosimetries of each type (same localization and technique), we define an initial reference state (IRS) from which we record the most representative dosimetry values of each dosimetry. For example, in the case of a prostate dosimetry, those values are the mean doses to OAR and the minimum dose to the tumor. We use the averages of these values and their standard deviations to calculate, with ad hoc equations and for each structure, two quantities that will play the role of D50 and γ in the

logistic and Poisson models, that define the complication to healthy tissue probability (CHP) and tumor control probability (TCP). The generated CHP and TCP curves are representatives of the considered dosimetries for the IRS and set the scenario where each future dosimetry will have its quality evaluated. By construction, these curves consider the variability between patients in terms of all the aspects that may influence the dosimetry quality.
We can now compute a quality index (QI) for each dosimetry that mimics the definition of tumor control probability without complications, QI≡TCP ∏(1−CHPi), and that can be compared with the IRS.
Thus, the IQ becomes a tool that will facilitate the task of knowing until when it is appropriate to optimize a dosimetry, based on what has been considered optimal until now. It will also allow knowing what the room for improvement is and the specific strategy to do it. Therefore, the IQ can monitor the evolution of the dosimetry quality, offering a method to control it, maintain it and, progressively, tent to improve it, regardless of the personnel, specialist, technician, or student, who has carried it out.

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DIY 3D PRINTED EBT3 APPLICATION FOR PTW WATER TANK

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The commissioning of a new linear accelerator for radiotherapy requires many measurements by medical physicists. A series of essential measurements are the output factors (O.F.) of the field sizes of clinical use. The measurement of the O.F. is complicated when measuring small field sizes with respect to the size of the detector and how these factors can be related to the reference field 10x10cm since many of these small detectors can only be used for small fields showing over or under response in large fields. The TRS483 provides correction factors for some ionization chambers and other detectors that can be used to measure these factors, in fact, the recommendation for the measurement of small fields is the comparison of several different detectors.
An adequate detector for the measurement of O.F. of small sizes is the EBT3 film, due to its high spatial resolution and low energy dependence. For the measurement of O.F. a PTW water tank with TRUFIX positioning system is used. This system positions the effective measurement point for various detectors on the water surface facilitating the workflow. The objective of this work was to 3D print a new adapter compatible with the PTW TRUFIX system in which after centering the water tank, the 3D printed applicator positions the film at the effective measurement point allowing the films to be irradiated for small field sizes inside the water tank. The printed support maintains the film perpendicular to the radiation beam, in a precise and reproducible position throughout the various irradiations. The results show that the applicator is compatible with the PTW TRUFIX system, and the films are positioned in a precise and reproducible way.

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IMPORTING THE DOSE FILE FROM A PLAN CREATED WITH PRECISION FOR CYBERKNIFE INTO ECLIPSE

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Two advanced planning systems for radiotherapy treatment in selected patients with a various kind of lesions are Eclipse from Varian and Precision from Accuray.
In our center we use Eclipse planning system for TrueBeam, Clinac DHX, Clinac Silhouette and Halcyon. And we also use Precision planning system for CyberKnife.
Therefore, since there are many times where it is needed the sum of different treatment plans to evaluate the global dose to the patient over time, we aim to export the files from Precision and import them into Eclipse in order to sum the dose delivered from the different machines.
According to the DICOM conformance statements, there is a common comunication standard for the dose files containing information about every plan, whatever machine or TPS we use. However, we found trouble with both TPS to be able to directly import the dose from the other planning system.
Eclipse has the feature of summing two dose distributions from different CTs, when having a rigid registration between them.
This TPS also has a dedicated module to perform the task of importing dose files from different TPS, but we dont have it, so we managed to create a protocol where we were finally able to successfully import Precision planning system dose into Eclipse.
In order to validate the process we checked the geometrical consistency in the export, the DVH and administrative data. We imported for 15 patients the respectives structure sets and doses and we carried out a Wilcoxon test that resulted on non significant statistical difference.
The process to follow included the creation of a virtual plan in Eclipse and modifications of certain DICOM headers, which have been changing depending on the different updates that the software of both systems have undergone over time.
For several years now in our center we have been using an ordinary program to handle dicom files, but lately we have been using Python to create, modify and copy sequences and elements in DICOM files according to the dicom conformance statement, to automate the necessary changes for the Eclipse planning system to accept Precision planning system dose files and speeding up this way the process.
This way of importing doses from one TPS to another, also makes it easier for us to compare plans made with different techniques, and thus be able to carry out interesting studies that might result in an evolution of the treatments performed.

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SCRIPT FOR COLLISION DETECTION IN EXTERNAL RADIOTHERAPY PLANNING

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Introduction: The increasing complexity of external radiotherapy treatments at our institution has led to an increase in the number of collisions during treatments. In order to avoid them, we have developed a script, integrated within the radiotherapy treatment planning system Eclipse, which warns of collisions at the treatment planning stage.
Method: The software has been written in the C# programming language, with the Application Programming Interface for Eclipse Scripting.
It is able to extract the information from Eclipse in order to simulate the treatment geometrically. In particular, it extracts the coordinates of the triangle vertices that form the mesh geometries for the structures representing the couch and the body of the patient. It also generates a series of coordinates that represent

the head of the accelerator. These coordinates are generated as a convolution of a circle (with the diameter of the collimator) with an arc of circumference (with a radius equal to the clearance), the later representing the movement of the gantry.
Once we have the two sets of coordinates (couch-body and accelerator head), we compute all possible distances between points from both sets. If one of these distances is less than 1cm, a collision warning and a scatter plot of the coordinates appears. To check that the script works properly, several treatments have been simulated covering all possible degrees of freedom: couch, gantry and different isocentre positions, with collision, without collision, etc.
Results: After testing the code in the aforementioned situations with a satisfactory result, the software has been straightforwardly incorporated into the planning workflow for external radiotherapy treatments. Currently, it is executed in every planning, as it provides an additional safety barrier before treatment. With it one manages to:

- Improve patient safety by further reducing the possibility of a collision with the treatment accelerator.
- Improve treatment equipment safety by reducing collisions between different parts of it (couch and gantry).
- Avoid the radiation dose already administered to the patient when the collision occurs after treatment start.
- Improve efficiency in the use of resources, avoiding replanning.

Conclusions: A script that warns of collisions of the accelerator head with the couch or the patient has been successfully included in our external radiotherapy planning routine. This improves the safety of the patient, the safety of the treatment equipment and the optimization of available resources.

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BRAINTOOL: A 3D PRINTED ANTHROPOMORPHIC PHANTOM TO TEST ACCURACY OF BRAIN RADIOTHERAPY TREATMENTS

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BrainTool is a homemade phantom designed to reproduce realistic CT and MR images of the human brain. The purpose of the phantom is to test the accuracy of brain radiotherapy treatments, which is extremely important when high doses are delivered in few fractions such as in stereotactic treatments and radiosurgery. A synthetic T1 weighted MR study of a human brain (https://brainweb.bic.mni.mcgill.ca/) was used to model the phantom. MR images were segmented, and skull, white/gray matter and ventricles were contoured; the simplified structures were then used to create 3D printable models. 3D printed parts were assembled to obtain four compartments filled with compounds and solutions that create realistic MRI and CT brain contrasts. Gypsum and beeswax give the phantom realistic HU and MRI contrast for skull and ventricles respectively. Different T1 or T2 MRI relaxation times for gray/white matter can be achieved by choosing different NiCl2 solutions to fill gray and white matter cavities. A silicon head modeled from a CT study of the phantom has been added to reproduce the surface of the human head and prevent radiation passing through sharp edges. Accuracy of images registration for patient positioning and image-guided radiotherapy systems can be tested using eight plastic markers distributed in the BrainTool. The registration accuracy is obtained measuring, for each marker, the difference between correspondent markers coordinates in the original and registered data sets for CT/MR and MR/MR. Point dose detectors (3D semiflex (PTW, Freiburg GmbH), or others) hosted in customized holders can be inserted in two cavities inside the phantom. The measured dose can be compared to the calculated dose to evaluate dosimetric accuracy of a treatment. In radiosurgery systems, a scanning procedure can be adopted to measure targeting accuracy.
This video will present the phantom realization and how the Braintool phantom was used to assess co-registration and accuracy of targeting for treatments with Gammaknife.

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GLOBAL AND LOCAL UNIFORMITY IMAGEJ MACRO FOR FLAT PANEL QUALITY ASSURANCE

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In this work, we present a macro tool for ImageJ to study global and local uniformity for average pixel value (AVP) and signal-noise ratio (SNR), for conventional x-ray images performed by digital flat panels. The uniformity value is calculated from the AVP and the standard deviation (SD) from two ROIs. These ROIs correspond to the maximum and minimum ROI's AVP in the case of global uniformity, and maximum and surrounding AVP for local uniformity.
The macro firstly inquires if linearization is required (lineal or logarithmic), and ask for the corresponding parameters (slope and offset). If there is no need of normalization, the default parameters must be kept. As following publication from Mackenzie 2008, the linearization affects ROI's AVP and SD values, rather than individual pixel values.
For the global uniformity, a 3×3 cm2 ROI navigates the 80% central section of the image in a similar way as the one used in the document IEC 62220-1 (Detective quantum efficiency) to characterize the noise power spectrum. The ROI traverses a horizontal row, half of it horizontally overlapping the previous position. Once finished the row, the ROI jumps to the next one, vertically overlapping the previous row. In this process, the macro keeps track of the maximum and minimum AVP. The final value is obtained by subtracting the maximum from the minimum AVP, and dividing by the average AVP of all the traversed ROIs.
In the case of local uniformity, the ROI cross the image in the same way as the previous case, but for the study it compares the current ROI with the combined-ROI consisting of the eight surrounding ROIs. Then, it subtracts the AVP of the central ROI from the AVP of the 8-surrounding-ROI region, and this value is divided by this last AVP for averaging. The maximum resulting value for the whole image is given as solution.

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DOSE REFERENCE LEVEL CLASSIFICATION TOOL WITH PYTHON

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Diagnostic reference levels (DRLs) are useful to verify that the diagnostic protocols of the x-ray equipment under our management optimize the dose delivered to the patient, achieving a correct image quality. To study these DRLs, we work with an extensive amount of data that must fulfill certain conditions like patient age, clinical protocol, body part location, etc. For this reason, determining DRLs in any non-small institution may be time-consuming. Henceforth, we have developed an automated code based on Python to analyze the data and to obtain a compendium of the results.
The programming language used in this work is Python because of its versatility. The module Pandas is used to deal with large amount of data by reducing memory usage and ultimately improving computational efficiency.
The code can be adapted to be fed with several files containing a single x-ray device data, or a single file containing all data. It automatically detects the x-ray modality (CT, conventional radiology or mammography) attending to the dose parameter contained in the file (CTDI or DLP, DAP or MGD). Various filters are applied to discard data such as non-clinical protocols (topograms, scouts, calibration…), age range, entries with empty critical data (e.g. dose parameter), or less abundant protocols (e.g. less than 1% of the total on each device).
The remaining protocols are grouped by location, considering the resemblance of the protocol name with body locations (head or brain with cranial location, lung or pulmonary with thorax location, …). To accomplish this, we use the concept of Levenshtein distance, which counts the number of letter changes (substitution, insertion or deletion) to convert one word into the other. Once these are grouped by location, a statistical analysis is performed, and the median dose parameter is computed to compare with the dose reference level.
The main advancement of this automated process is to classify the different diagnostic protocols with their corresponding body locations. These protocols are named diversely in different devices even in the same institution. Thanks to the algorithm based on Levenshtein distance, the majority of the protocols are correctly identified, although the work to enhance the performance is still in progress.
Python automated algorithms combined with modules as Pandas are very versatile tools to work with large amounts of data. With these kinds of homemade programs, European institutions may save a lot of time in the future when setting their DRLs.

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FULLY AUTOMATED REMOTE QUALITY CONTROLS FOR RADIOLOGY EQUIPMENTS FOLLOWING IAEA HUMAN HEALTH SERIES NO. 39

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The International Atomic Energy Agency (IAEA) recently has published a report about the implementation of a remote and automated quality control programme for radiography and mammography equipment (IAEA HUMAN HEALTH SERIES No. 39 [1]). Users can analyze images of a home-made phantom following IAEA specifications using software published by IAEA itself [2]. A published study [3] tested the phantom and the software in four institutions in Costa Rica and the United States of America.
In this work I developed a software architecture for testing the possibility to fully automate the entire remote analysis and display the results.

Material and methods: I first wrote a java program to replicate the results of the IAEA software and write the results on a database. This program automatically detects the phantom regions of the images suitable for the analysis. The database was designed and configured using the python Django framework, which allows CRUD operations (Create, Read, Update and Delete) on the database using a web page (admin pages).
An Orthanc Server (Open Source DICOM Store PACS) was deployed to receive the images from the remote modalities (remote PACS archives and/or remote radiological equipment). Every single received instance triggers the local saving of the image and the execution of the java program. The data saved on the database can be analyzed separately. I also wrote a small web application using node.js Express server as a backend and a Quasar (Javascript framework based on Vue.js) frontend along with Charts.js for displaying time-series charts of the analyzed parameters. The java program saves MTF values (MTF_{50}, MTF_{20} and MTF_{10}), the signal, SNR and SDNR values, the detectability indices for 0.3 mm and 4 mm detail diameter, along with the exposure parameters: mAs, exposure index (EI), target Exposure Index (EIt) and deviation index DI.
Results: Every time an image (with specified related information such as Patient Name and/or Station Name etc.) reaches the Orthanc PACS, the java program does the analysis and saves the results on the database. The web application displays the charts correctly. I also add the possibility to specify on the database which record represents the baseline values. The charts display baseline values and ±15% horizontal lines (control charts).
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MACARON: DATA COLLECTION AND MACHINE LEARNING TO IMPROVE RADIOMICS AND SUPPORT RADIATION ONCOLOGY

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In radiation therapy, several information as personal data of the patient, clinical record, diagnosis, radiological CT images, type of treatment, dosimetric parameters and Quality Assurance (QA) results are being gathered for each patient who undergoes treatment. Unfortunately, medical personnel and medical physicists struggle in conducting analyses and having a comprehensive view since those data are usually scattered across different software or databases.
MACARON makes a step towards automatizing the data collection and analysis process: this open-source framework aims at building a high-quality dataset of clinical data to conduct correlation, regression and prediction analyses that will improve radiotherapy treatment quality and efficiency. First, MACARON automatically extracts and computes data coming from heterogeneous sources, storing them in a unified and privacy-preserving database. Then, it provides a platform to conduct correlation and prediction analyses through machine learning: this allows discovering correlations

between different aspects of a treatment e.g., dosimetric data and treatment outcomes, treatment characteristics and QA results, radiomic features and disease evolution.

Our video contribution shows the data that MACARON collects from different input sources – mostly CT, RT-plan, RT-dose and RT-structures DICOM files, plus QA Comma-Separated-Value (CSV) files – and stores it in a dataset for fast analytics. During this process, MACARON automatically computes a large amount of aggregated information:

1) Dose-Volume Histograms (DVH) for each contoured structure, which are stored both as CSV and image files; those are complemented with additional dosimetric user defined indexes such as the percentage of dose that covers specific structure volume during a treatment
2) Radiomic Features are extracted for each structure by processing CT images. Those are numeric values grouped according to their type (first order statistics, shape-based, grey-level matrix…)
3) Complexity indices such as aperture irregularity, modulation complexity score, and mean field area are calculated and stored as CSV files

Parts of those functions build on the existing PyRadiomics and PyDicom libraries that we integrated into MACARON via BSD-3 licensing, whereas most of the connectors to non-DICOM source files were newly implemented. All the information being extracted, transformed, and computed through the framework are stored into a MySQL database for indexing and fast retrieval and analytics. Currently, the MySQL database contains more than 20 tables and many stored procedures that provide APIs (Application Programming Interfaces) for storing and retrieving aggregated data.

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MANAGING HIGH DOSES IN INTERVENTIONAL PROCEDURES USING MATLAB AND DICOM RADIATION DOSE STRUCTURED REPORTS

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In order to estimate the peak skin dose delivered to patients during interventional procedures, looking for potential skin injuries, we have developed a Matlab application that processes the information contained in the DICOM dose structured report to estimate the skin dose map and the peak skin dose. The web application, called Dicom Dose (DIDO), is deployed by the Matlab web app server and it is accessible by any medical physicist from our organisation (the Madrid Health Service).

Through the technical information from each irradiation event (field size, table position, beam energy, etc.) the software estimates the skin absorbed dose at an anthropomorphic phantom (body or head), taking into account air kerma at the interventional reference point, the focus-skin distance, the mass-energy absorption ratio, table attenuation (T) and backscattered radiation (BSF), all of them as a function of beam quality (HVL) and beam size (bs).

The system can provide, under user request, up to 50 different male and female phantoms depending on patient age and size. If no information on the weight and height is provided, the calculation is performed in a cylinder with an elliptical base of 150×300 cm axes. DIDO estimates de skin dose map splitting the radiation field in beams and projecting them at the anthropomorphic phantom to estimate the dose for each surface element. DIDO is currently linked to our dose management system, accepting the information in a csv specific format. As advantages, it allows to calculate several procedures simultaneously making the calculation in less than 1 minute (8-15 events/second). It generates a 3D skin dose map, the peak skin dose and gives de possibility of printing a report of the processed data and the results. The accuracy has been proven to be below 15% in neurological interventions and simple projections.

Some system's limitations are the incapacity for modelling complex examination couches (some models are thinner towards the head of the patient) and the absence of information on the patient position which may result in a shift in the x-z plane between the actual dosimetric map and DIDO's estimation.

With the help of an accurate skin dose mapping system, it is possible to reduce the number of cases that require follow-up for potential skin injuries.

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A NOVEL ATTACHMENT SYSTEM FOR CUTOUTS IN KILOVOLTAGE X-RAY BEAM THERAPY

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Standard applicators in kilovoltage x-ray beam therapy rarely actually fit to the shape of the target volumes. Therefore, customized shielding enclosing the target volume to spare healthy tissue is nowadays mainly based on in-house cutouts attached to applicators or patients. The production of customized shields could be time consuming and inaccuracies during the replacement of cutouts may arise if the same applicator is required to treat different patients or target volumes immediately one after the other. An adequate, fast and reproducible approach of an attachment system was developed to treat target volumes in the low and medium energy (kV) range for standard applicators.

At the University Hospital Basel, 60% of all in-house shields were carried out with straight-lined cutouts. They were coated with a plastic foil to prevent skin contact with the toxic cutouts and the produced secondary electrons. A frame-based system to attach customized shields to the applicator could be a decent solution for the reproducible and sustainable use of cutouts. One requirement in the developing process was that there is no interference of the radiation field with the mounted frame of the shielding system nor any manual force or change of applicator applied to mount the frame.

For the attachment of the cutouts to the applicator VELCRO® strips (hook-and-loop fastener) were glued to a PMMA frame with an identical size of the applicators exit window which can be attached to VELCRO® strips elongating around the applicator itself. The skin facing side of the frame was also covered with VELCRO® strips. Straight-lined cutouts covered on the one side with VELCRO® strips and on the other side with a plastic foil can be adjusted within seconds to shape the straight-lined target volumes.

All used straight-lined shields from the patient database were retrospectively successfully replicated to confirm the feasibility of this frame-based system. It must be considered to perform preclinical measurements or apply the inverse square law in order correct for the increased distance of the applicators surface to the patient skin caused by the attachment set-up and cutout to the prescribed dose. The advantage of this frame-based system is a fast and reproducible attachment of customized shields without damaging the applicator. This novel approach could extend the features of a kilovoltage treatment unit to irradiate multiple target volumes in a row with the same applicator but different frames and cutouts with user-friendly exchangeability.

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A DOSIMETRIC DOSE EVALUATION OF FILM USING AN OPEN SOURCE APPROACH

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It is still common to use radiosensitive films for dosimetric evaluation of dose distributions in quality assurance (QA) phantoms respectively patient specific QA procedures. Commercial software for the evaluation of such films can be expensive but at the same time very handy for comparison with dose planes exported from treatment planning systems. Most often they offer many additional sophisticated features as gamma evaluation methods or the generation of reports for purpose of recording. Nevertheless, the open source ImageJ program (Java-based image processing tool) provides all the basic features necessary for a decent dosimetric dose evaluation of Gafchromic EBT2 films following the vendors requirements to a get proper dosimetric outcome. A very simple but efficient approach of using ImageJ will be presented followed by a film comparison with a commercial software.

For the generation of calibration curves the recommended red-channel method can be applied and for each calibration film, dose values can be assigned to measured grey values. Hence, a calibration curve can be generated and fitted either with the recommended rational function from Gafchromic or the already available Rodbard function in ImageJ. Once the calibration data is set an additional plug-in (Contour_Plotter.jar) for better visualization of isodose lines can be loaded.

A comparison of the evaluation of the percentage dose distribution of 6MeV electron energy between the open source approach with ImageJ and the commercial software FilmQA has shown reliable results. This very simple approach provides a fast, cheap and independent evaluation method of dosimetric films used for clinical QA procedures. Further investigation needs to be done if a gamma evaluation method can be implemented by writing more sophisticated macros for a more enhanced evaluation.

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SMALL CUSTOMIZABLE VESSEL MODELS FOR 3D PRINTED ANTHROPOMORPHIC PHANTOMS: AN OPEN CODE SOLUTION

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The inception of 3d printing in medical physics, in particular as a manufacturing technology for customized test objects or phantoms is growing. There is a need for realistic anthropomorphic phantoms that mimic the X-ray attenuation of patients' tissues and their anatomy and morphometry. The evaluation of accuracy and reproducibility of 3d printing techniques for phantom creation is a field under development.

We present a simple open code, based on Matlab, to generate customized models of small vessel trees that could represent to some extent lung or liver vessels. The user can select the number of vessel generations, angles, radius and lengths (either via a pop-up input window or manually in the code itself), within certain constrains. A support platform can also be optionally added to help the vessel structure stability during the printing process. As output, STereoLithography (STL) files are generated, which can be imported in a 3D printer of choice to create an object.

Such code can help medical physicists to: (1) start learning at a small scale about the mathematical generation of simple vessel-like anatomical structures, (2) have access to affordable small anatomical-like test objects to evaluate different 3d printed materials and techniques and (3) study the performance in terms of accuracy and reproducibility of 3d printers based on physical measurements on an anatomical and simple object.

The gold standard provided by the mathematical model can also be compared to the printed objects or medical images of them to evaluate the printing process. As the generated test objects are relatively simple and small, physical measurements, for instance measurement of radii or lengths with vernier calipers in the printed vessels can be performed to evaluate or compare different prints, methods and materials.

As the code is open-source software, potential users can customize the vessel models further, including specific functions to control the radius and length of vessels or generating several small tree branches in the same volume. The models generated in the presented code are intented for educational purposes, providing a simple and open implementation of modelling anatomical structures to be combined with 3d printed techniques.

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AN EVALUATION OF OUTPUT FROM A UVC DISINFECTION SYSTEM

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Purpose: UVC radiation has been proven to kill known pathogens and recent years have seen increased adoption of UVC disinfection technology in healthcare settings in an effort to limit the spread of COVID-19 and other common hospital-acquired infections. European Council Directive 2006/25/EC outlines the maximum permissible exposure (MPE) levels for workers due to artificial optical radiation. Knowing the output of a UVC disinfection system allows us to better quantify the risks however this quantitative information is not readily available to the user for some systems. The purpose of this study was to measure the output of a UVC disinfection system used in a hospital environment using a light meter calibrated for the UVC range.

Material and methods: The THOR UVC disinfection system (Finsen Technologies Ltd, UK) was used for this study. This system uses 90-watt TUV PL-L mercury lamps (Philips Lighting, UK) which emit UVC light at 254nm. It features 24 bulbs around a central column, and the system is controlled remotely via a tablet interface.

An ILT2400 light meter (International Light Technologies, USA) calibrated for the 254nm UVC range was mounted on a tripod. The output was measured under different conditions to determine repeatability, consistency, and variation with height, distance, orientation, and exposure time. Unless stated otherwise the measurements were taken at a distance of 1m and a height of 1.5m. The test area chosen was representative of the maximum size of a patient room with an area of 31m^2.

Results: The mean maximum output of the system was 2.2±0.1 mW/cm^2. This was found to be consistent over a period of 25 minutes. These results were used to calculate the time to reach the MPE (T[MPE]). The output at a tower orientation of 0° and 180° was found to be 22% higher than those at orientations of 90° and 270°.

Conclusions: Using these quantitative results, it was possible to determine the maximum permissible exposure time for the UVC radiation emitted from this system. The observed variations in system output due to contributions of scattered radiation, system

orientation, and height may have implications for the degree of disinfection achieved. The T[MPE] of 2.6 seconds based on these measurements was 20% lower than the value estimated. The orientation of the system was shown to impact the T[MPE].

These results highlight that a multidisciplinary approach which includes Medical Physics should be taken when introducing these systems to a hospital environment.

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