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Session 1 | Automated Workflow in Radiotherapy

F1 Automated contouring and treatment planning

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Automation of repetitive processes is essential for improvements of efficiency in radiation oncology workflows. Besides an improvement of efficiency, also the homogeneity of the generated data (e.g. contours and treatment plans) of the patient cohort will improve. This lecture will provided an overview of automation techniques for contouring and treatment planning. Techniques for testing, evaluation and implementation of these automation concepts will be discussed.
Automated QA: machine and patient specific

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Quality assurance in radiotherapy ranges from chart checking including the inspection of prescribed dose, Monitor Units, machine parameters, patient information etc. to verification of field size, MU/Gy calibration, symmetry and flatness of both photon and electron beams, accuracy of (dynamic) treatment delivery etc.

Both machine and patient specific QA procedures include a wide variety and complexity of different steps; thus QA can be expensive and time consuming. Moreover, these manual procedures are prone to human-related errors. Automation of QA procedures could provide faster, more reliable and more efficient ways to ensure patient safety.

In this presentation, an overview of methods for the automation of patient specific measurement based dose verification and calculation/simulation-based dose verification will be given. Solutions for the automation of machine specific QA will be discussed.

Additionally, a clinical strategy using automated QA processes will be presented for both patient and machine specific QA. In this clinical setting for patient specific QA, both in-house developments and commercial solutions are merged to increase efficiency in routine processes. For machine specific QA, one of the commercially available solutions will be discussed.
Introduction
With the new radiation protection legislation, it is the task of the medical physicist to monitor and optimize the dose of CT examinations [1-3]. How can medical physicists determine the necessity for optimization of a protocol and how should they proceed?

Materials & Methods
At first the dose of the CT examination is monitored with the help of a dose management system. In a second step the dose is compared to the diagnostic reference level (DRL) [4-8] for the specific procedure. When the dose (CTDI or DLP) is frequently higher as the diagnostic reference level the protocol should be optimized by changing CT scan parameter. To illustrate the process, the dose management of CT examinations, the optimization of the brain perfusion protocol and the use of DRL and achievable levels on behave of their use in optimization process are presented. It will be finally underlined that optimization of CT protocols should be performed considering the new concept about “clinical diagnostic reference level”.

Results
The optimization process in CT imaging requires specific software tools, understanding how to use diagnostic (and achievable) levels and detailed knowledge of the CT scan parameter and the diagnostic procedure.

Summary
The responsibility for medical physicists to optimize CT imaging results in dose monitoring, a comparison with diagnostic reference level and an optimization of the scan parameter, when the levels are frequently exceeded. The optimization process should only be done in agreement with the physician and the manufacturer of the CT.

References
**Session 3 | Dosimetry in Precision Photon Radiotherapy 1**

**V1** Lateral dose response of an ionisation chamber in an external magnetic field

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**Introduction**

Ionization chambers in hybrid MRI-Linacs have a different response compared to conventional radiation fields due to the spiral path of the electrons in a magnetic field. In this study, the impact of an external magnetic field on the spatial response within an ionization chamber was investigated with Monte Carlo simulations.

**Materials & Methods**

The SNC 125c ionization chamber (Sun Nuclear Corp., Melbourne, USA) was modeled in detail with the C++ class library of the EGSnrc Monte Carlo code system and placed in a water phantom at a depth of 10cm. The spatial dose response was calculated by scanning the ionization chamber with a 6MV and 18MV pencil beam (Ø = 0.2mm) in lateral direction. For each position of the pencil beam the average dose within the air-filled cavity was calculated. All calculations were performed with and without a magnetic field of 1.5T.

**Results**

Figure 1 shows the 2D response without (a) and with an external magnet field perpendicular to the beam and symmetry axis of the ionization chamber (b). For B = 0T the dose response within the air-filled cavity is more or less homogeneous, the central electrode and especially the guard ring show a clear overresponse due to electrons released by photon interactions within these high-Z components. In the presence of an external B-field, the electron trajectories are changed due to the Lorentz-force, resulting in non-symmetric dose distributions within the cavity.

**Summary**

In this study the 2D-dose response of the SNC 125c ion chamber was determined via Monte Carlo simulations with an without external magnetic fields B. The results may help to understand the perturbations in ion chambers due to external magnetic fields B.

**Appendix**

![Figure 1: Two-dimensional dose response function of the SNC 125c ionization chamber for a 6 MV photon beam, a) B=0T, b) B=1.5T.](image-url)
Angular dependence of ionisation chamber perturbation factors irradiated with an 192Ir-brachytherapy source

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Introduction
Dose measurements in the vicinity of an 192Ir-brachytherapy source using a point detector are commonly performed in a well-defined geometry with fixed detector orientation and distance from the source. However, treatment plan verification or profile scans involving spatial characterization of 3D dose distributions may be performed using different detector setups. In this work, the angular dependence of the chamber dose response is studied in terms of its perturbation factors.

Materials & Methods
Two ionization chambers (PTW PinPoint3D 31016 and PinPoint3D 31022) were investigated. The angular dependence of their dose response was simulated using EGSnrc by moving the source in a circular path around different rotation centers lying along the radial and longitudinal chamber axes. The simulated dose response in 10° step was normalized to that at the reference position (α = 0°), in which the chamber tip was pointing towards the source with the chamber axis and the source center aligned in a straight line. At α = 0°, the front surface on the chamber tip side was positioned at 2.5 cm from the source. Simulations were performed with the complete chamber models and models modified stepwise to study the angular dependence of the perturbation factors associated with different chamber components.

Results
The dose response of the investigated chambers was found to depend on both the angle of incidence α and the location of the rotation center. For both chambers, the volume-averaging effect causes a variation of dose response up to about 5 % at large angles. The largest perturbation effect contributing towards the angular dependence is caused by the low-density air cavity.

Summary
The angular dependent dose response of ionization chambers must be taken into account when performing dose measurements of 192Ir-brachytherapy source involving different detector setups.
Introduction
The multi-axis ionization chamber array IC PROFILER (Sun Nuclear Corporation) in combination with quad wedge accessories has the potential to simplify the acquisition of linear accelerator beam data such as beam quality specifier. The aim of this work was to develop a Monte Carlo based model of this ionization chamber array to investigate the array in high energy photon beams.

Materials & Methods
This model of the detector array with 251 cavities and quad wedge accessories were developed in detail according to manufactory drawings using the egss++ class library from the EGSrnC code system. Figure 1 shows a cross section of the developed model. The calculated dose distributions in principal $D_{p,x}$ and $D_{p,y}$ as well as diagonal directions $D_{d,p}$ and $D_{d,n}$ behind the wedges were investigated in a 6 MV Elekta Precise radiation field to calculate the dose area ratio DAR:

$$\text{DAR} = \frac{D_{p,x} + D_{p,y}}{D_{d,p} + D_{d,n}}$$

Results
The dose area ratio was calculated from principal and diagonal dose profiles for linac’s with varying electron beam spot sizes 1-3 mm full-width-at-half-maximum (FWHM) with electron energies in the range 5.75-6.5 MeV (see figure 2).

Summary
A Monte Carlo based model of a detector array with quad wedges was created to investigate the possibility of determining the radiation quality from dose profile measurements. A linear relationship was observed between DAR and the beam quality specifier %dd(10), with $r^2=0.90$.

Appendix

Figure 1: Cross sections of the IC Profiler Monte Carlo based model. A cross section with two of the four quad wedges is shown on the left and a cross section through the chambers on the right. The image is not scaled.
Figure 2: Calculated dose area ratio as a function of the beam quality specifier %dd(10), for the Elekta Precise 6 MV linac with varying electron beam spot size FWHM and electron energy.
Investigation of the behavior of diode-type detectors in small fields under the influence of a magnetic field

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Introduction
Magnetic field correction factors under reference conditions have been studied for ionization chambers and diode-type detectors. The aim of the present work is to investigate the behavior of two diode-type detectors (PTW microDiamond 60019 and PTW microSilicon 60023) in a magnetic field under small field conditions.

Materials & Methods
Measurements were performed at the National Metrology Institute of Germany (PTB, Braunschweig) using a 6 MV photon beam of a clinical linear accelerator. Quadratic fields corresponding to equivalent field sizes \( S \) between 0.63 and 4.27 cm at the measuring depth were used. The magnetic field was varied up to 1.4 T. Experimental results have been complemented with Monte Carlo simulations up to 1.5 T. The dose response, small field output correction factors and perturbation effects as well as the influence of detector components on the dose response have been studied.

Results
At 1.5 T, the dose response of both detectors decreases by about 10% in the largest field size and about 4% in the smallest field size investigated. The Monte Carlo results agree better than 1% with the experimental results. Due to normalization at \( S = 4.27 \) cm, the small field output correction factors in magnetic field are smaller than those in the magnetic field-free case. For the microSilicon, correction up to 6.2% is required at 1.5 T in \( S = 0.63 \) cm. The volume-averaging effect was shown to be independent of the magnetic field. The detectors behavior in magnetic field was found to be influenced by their enhanced-density components, but the effect becomes weaker with decreasing field size.

Summary
The dose response of both detectors decreases with increasing magnetic field for all field sizes investigated. The enhanced density components within the detectors have been identified as the major contributors to their behavior in a magnetic field.
Real-time in-vivo dosimetry for external beam radiotherapy using a novel inorganic scintillation detector

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Introduction
The purpose of real-time in-vivo dosimetry in external beam radiotherapy (EBRT) is to monitor and record the dose received by individual patients, provide an overall assessment, and can point out in real-time major systematic errors that could not be detected by other quality assurance checks.

Materials & Methods
We evaluated the feasibility of the use of a novel scintillation detector proposed by DoseVue N.V. for clinical in-vivo dosimetry. The technology is based on a submillimeter fluorescent scintillator that is mounted on a compact optical fiber and can be positioned on patient skin or introduced in natural or surgical cavities. Prior to clinical measurements, the dosimeter was calibrated in reference conditions, and tested in various and well-defined configurations using water-equivalent phantom.

Results
The detector appears to be energy-dependent for fields bigger than 5x5cm². After measurements in reference conditions, it shows consistent and reproducible results. For 6MV photon on phantom, the measured dose deviates from the treatment planning system (TPS) calculation by less than 3%. One clinical test has been performed on patient in a nasal cavity, and the measured dose differs by less than 5 % compared to the calculated dose. For 100kV photon in reference conditions, the measured dose from the scintillator agrees well with the results from thermoluminescent dosimeters (TLD), with less than 2 % of discrepancy. One clinical test has been performed on patient for a skin treatment, and the measured dose shows a deviation of less than 10% compared to TLD.

Summary
Such a scintillator is promising for real-time in-vivo dosimetry, and may have the potential to replace TLD in some cases. More clinical tests are expected to be done in the near future, especially on single fraction prostate stereotactic radiotherapy by placing the scintillator directly inside the patient body, via a urethra catheter.
**V6**  Dosimetric characterisation of liquid-filled ionisation chamber array OCTAVIUS detector 1600SRS

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**Introduction**
The high-resolution liquid-filled ionization chamber array OCTAVIUS Detector (OD) 1600SRS was introduced as an extension to the OD1000SRS (both PTW Freiburg), with an increased chamber number (1521) covering an enlarged measurement area of 15 \( \times \) 15 cm\(^2\). This study characterizes the new array.

**Materials & Methods**
Measurements were performed at an ELEKTA Synergy linac with 6 and 15 MV photons. The EPOM was determined by comparison of TPR curves measured with the 1600SRS and a reference Roos chamber. Measurements of the stability, inter-chamber sensitivity and dose linearity were performed at 5 cm depth and a SSD of 100 cm using a 10x10 cm\(^2\) field. The dose-per-pulse dependence was investigated by varying the SSD, the energy dependence was determined by varying the field size (4x4-20x20 cm\(^2\)) and depth (2-20 cm). The detector response was compared to that of a corrected Semiflex 31013 chamber. Patient plan verifications of stereotactic radiations of on- and off-axis targets were performed in the OCTAVIUS 4D phantom.

**Results**
Stability (0.2 \%), dose-linearity (0.5 \% over a dose range of 0.001-32 Gy) and inter-chamber sensitivity (0.45 \%) of the 1600SRS are comparable to that of 1000SRS. The EPOM was found to lie at 9.3 mm below the front surface. The maximum chamber response deviation due to changes in the photon spectrum was less than 3.2 \% for all investigated configurations. For very small targets, gamma passing-rates (local, 2mm/2 \%) were found to be slightly lower than those obtained using the 1000SRS, mainly due to the increased evaluated measurement points in the low dose region.

**Summary**
The OD1600SRS with increased coverage area offers the possibility to verify stereotactic radiations of larger or off-axis targets with high spatial-resolution. The observed issues, especially in low-dose regions of the reconstructed data, need to be further investigated to estimate their impact on plan verifications.
Session 4 | Adaptive Radiotherapy – Automation

V7 Clinical feasibility of autonomous planning for adaptive MR-guided radiotherapy of prostate cancer

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Introduction
Workflow automation is a key part of online adaptive radiotherapy (RT) as applied with hybrid MR-Linacs. We recently proposed an autonomous workflow, which integrated contouring, target generation and plan optimization for MR-guided-RT of prostate cancer. In the current study we aim to evaluate clinical feasibility in a patient cohort, presented as blinded assessment by radiation oncologists, where results of this autonomous approach were scored.

Material & Methods
For n=10 retrospectively selected intermediate risk prostate cancer patients treated at the 1.5T MR-Linac (20x3Gy), the planning CT was automatically annotated using an AI-based software (ArtPlan, TheraPanacea), targets were generated using logical volume operators and automatic planning was based on particle swarm optimization (figure 1). Blinded results were assessed by 5 board certified radiation oncologists. For this, the quality of the three independent automatization steps was scored on a 4-level Likert-scale (1-no, 2-minor, 3-major amendments, 4-not usable).

Results
In total, physicians agreed in 78% of all cases with the contoured OARs (mean score 1.7), in 66% with the CTVs/PTVs (2.1) and in 90% with the plan (1.4). Scoring results for the 10 patients are presented in figure 2. With respect to automatic OAR contouring, bowel bag was most likely to be identified as needing improvement. In 7, 8 or 2 cases the prostate, seminal vesicles or both contours were considered as improvable. Scoring for minor/major changes or complete failure was inconsistent among physicians. 5/50 plan scores were 3 or lower and therefore considered as inadequate for online adaptation, due to weaknesses in rectum dose sparing or PTV coverage.

Conclusion
Overall, the quality of autonomous planning for MR-guided-RT appears acceptable but needs further improvement. Contouring of highly variable OARs and targets should be improved e.g. by inclusion of MRI for better soft-tissue contrast. Furthermore, automated workflows integrating AI require human checkpoints for patient safety.

Autonomous planning workflow

Fig. 1: Representation of the three independent steps which were automatically conducted during the autonomous workflow.
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a) OAR contouring: Automatically contoured organs at risk (rectum, bladder, perire bulb, femoral heads and bowel bag) can be used without any adjustment for the planning process as baseline plan for an online MR-guided-RT.

b) Target volumes: Automatically contoured prostate and seminal vesicles are correct and the CTVs/PTVs generated from these contours by logical volume operators can be used without any adjustment for the planning process of a baseline plan for an online MR-guided-RT.

c) Planning: The automatically generated plan is usable as baseline plan for an online adaptive MR-guided-RT.

Fig. 2: Scoring of the three independent workflow steps. Subfigure a) OAR contouring, b) target generation and c) automatic plan. Scores 1-2 resume agreement, scores 3-4 disagreement.
Introduction

Daily variations in patient positioning, anatomy, and dose delivery lead to uncertainties in cumulative delivered doses. An automated evaluation of the daily treatment dose allows the therapist to adapt the treatment plan early when dosimetric errors or anatomical changes occur. We introduce an automated workflow that enables fraction-wise dose recalculation on daily imaging based on linear accelerator (linac) logfile data.

Materials & Methods

Based on treatment logfiles and the corresponding daily cone-beam CT (CBCT), a total of 157 treatment fractions from seven different prostate cancer patients were retrospectively evaluated with respect to dosimetric accuracy. First, CBCTs were converted into synthetic CTs (sCT) with a cycle-generative adversarial network-based based proprietary research toolkit (ADMIRE, Elekta). Afterwards, organ structures were transferred from the planning CT to each sCT via deformable image registration. Additionally, treatment logfiles were acquired for every treatment fraction and converted into a DICOM RTplan file. Using this data, the dose for each fraction was recalculated automatically with a Monte Carlo based dose algorithm, using a scripting interface (Monaco 6.0β, Elekta). The median dose D50\%, the near-minimum and near-maximum doses D5\% and D95\% for the planning target volume (PTV), as well as the V50Gy and the D5\% for rectum and bladder were analyzed.

Results

All dose recalculations showed good agreement of the target D50\% to the original treatment plan \(\Delta D_{50}\% (\text{PTV}) = (1.0\pm 0.5)\%\) (\(\Delta D_{50\%\max (\text{PTV})} = 2.0\%\)). The same applies for the near-maximum-dose-deviations \(\Delta D_{5}\% (\text{PTV}) = (1.2\pm 0.5)\%\) (\(\Delta D_{5\%\max (\text{PTV})} = 2.2\%\)). However, due to morphological changes the near-minimum dose \(\Delta D_{95\% (\text{PTV})} = (-2.7\pm 6.5)\%\) (\(\Delta D_{95\%\max (\text{PTV})} = 38.1\%\)) revealed relevant deviations. Organs at risk doses were, for most cases, close to the original treatment plan doses \(\Delta V_{50\% (\text{bladder})} = (1.8\pm 0.7)\%\), \(\Delta D_{5\% (\text{bladder})} = (0.6\pm 1.0)\text{Gy}\), \(\Delta V_{50\% (\text{rectum})} = (0.4\pm 1.0)\%\), \(\Delta D_{5\% (\text{rectum})} = (+0.4\pm 3.8)\text{Gy}\) with one exception of rectal doses exceeding the planned dose markedly \(\Delta D_{5\% (\text{rectum})} = +5.8\text{Gy}\) because of varying rectal filling.

Summary

The presented method can automatically recalculate daily doses and allows for case-to-case-based decision making when dosimetric deviations warrant treatment plan adaptation.
V9  Autonomous robotic ultrasound probe positioning for ultrasound guided radiation therapy

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Introduction
One of the central problems of radiation therapy is the position monitoring of tumors during radiation. A new approach is intrafractional robot-assisted, ultrasound-guided tumor imaging (USgRT). Ultrasound (US) requires constant contact pressure and good positioning of the transducer. In this study we present a solution for a safely positioned US probe autonomously by a robotic arm.

Material & Methods
A software platform was designed combining the robot, the ultrasound device, a tracking camera and a force reference sensor. The tracking camera was used to define the robot coordinate system in the room and register those with the planning image data of the patient. Based on the patient planning data an initial position for the US probe was designated in the developed robot control software. Different placement trajectories for different target positions were tested and checked for their clinical usability. This also included cooperative approaches with the technicians using a self-developed haptic control of the robot. In addition, exceptional situations (collisions) were generated, and sensor values (robot, force sensor) were recorded. These were used to train an algorithm to recognize dangerous situations. Based on this, feasible reactions of the robot to the exceptional situations were tested.

Results
The tests reveal that a safe, autonomous positioning of the US probe by the robot is realizable. The desired image plane is approached reliably and repeatably. Suitable approach trajectory could be found for different target positions. The trained algorithm reacts immediately to unexpected events such as collisions. Injuries of staff or patient are prevented due to a real-time response of the robot.

Summary
The results clearly show that to define a desired sound position in the planning images and to approach this fully autonomously as well as in cooperation with the technician. The process is fast, safe and enables clinical use in future.
**V10** New concept for image guided intraoperative radiotherapy with a novel cone beam computed tomography (CBCT)

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**Introduction**
Linac-based intraoperative radiotherapy with electrons (IOeRT) is implemented to irradiate directly tumours or tumour beds during cancer surgery. A new type of mobile CBCT (ImagingRing-m, medPhoton) system shall be used before the application of Radiation in order to enable a better estimate in 3D dose distribution, also aiming at integration into total dose plans with preceding or following EBRT. In combination with a modified new dedicated IOeRT Linac (Mobetron, Intraop Medical Ltd) the components are coordinated to each other and the workflows are optimized. The first clinical trials for this image-guided IORT with CBCT are presented.

**Materials & Methods**
A fix flour mounted dedicated IORT Linac uses three different electron energies (6, 9, 12 MeV), which can be mixed together individually. IORT Tubes made of fully capable material without metal components are used in combination with a radiolucent mobile patient couch. The difference between conventional metal tubes and radiolucent tubes are compared. A dose distribution is calculated based on pixel value corrected CBCT image data set. Dosimetric and geometrical phantom measurements are carried out.

**Results**
The dosimetrical difference between conational metal tubes and radiolucent tubes are within 2%. The calculated dose distribution based on the CBCT match the defined clinical goals and the comparison between 1d PDDs and a 3d estimate is within the expected range.

**Summary**
The introduction of CBCT seems to be a new evolutional way in the IORT to bring more quality and accuracy in dose estimation.

**References** (if applicable)
Introduction

Within a clinical study, we investigate the potential benefit of prompt-gamma-imaging (PGI) based range verification in proton therapy. As the manual interpretation of detected spot-wise range-shift information is time-consuming and complex, we aim to automatically detect and classify treatment deviations from realistic PGI data using convolutional neural networks (CNNs).

Materials & Methods

For 12 head-and-neck cancer patients and an anthropomorphic head phantom, monitoring of single fields from pencil-beam-scanning plans with the IBA slit camera was considered. In total, 386 treatment deviations were simulated on planning and control CTs and manually classified into 7 classes: non-relevant changes (NRC) and relevant changes triggering treatment intervention due to range-prediction errors (±RPE), setup errors in beam direction (±SE), anatomical changes (AC), or a combination of such errors (CE). The spatial maps of filtered PGI-determined range deviations were converted to 16x16x16 voxel grids. Three complexity levels were investigated using 3D-CNNs [training cohort (n=9), test cohort (n=4), Fig.1]: (A) optimal PGI data, (B) realistic PGI data with simulated Poisson noise based on the locally delivered proton number, (C) realistic PGI data with additional positioning uncertainty of the slit camera.

Results

During validation on the independent test data, the 3D-CNNs achieved multi-class accuracies of 81 %, 77 %, 76 % and binary accuracies of 97 %, 95 %, 93 % for the respective complexity levels (A,B,C) (Fig.2). In the most realistic scenario (C), relevant treatment deviations were detected with 97 % sensitivity and 82 % specificity. Misclassifications of the AC class were caused by similar PGI characteristics of the CE class.

Summary

CNNs can reliably detect and classify relevant treatment deviations from realistically simulated PGI data. While validation on measured patient data is needed, our study highlights the potential of automated PGI interpretation, which is desired for broad clinical application and a prerequisite for including PGI in an automated feedback loop for online adaptation.
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Appendix 1

Fig. 1: Schematic of the study design. Training of the CNNs using patient-wise leave-one-out cross validation was carried out on an exploratory cohort (n=9) which resulted in 9 models. The final performance of the ensemble of CNNs was evaluated on an independent test cohort (n=4) using multi-class as well as binary accuracy as metrics.

Appendix 2

Fig. 2: Illustration of the three complexity levels (A), (B), (C) in terms of PGI profiles (top) and 10x16x16 voxel grids used as input for the CNNs (middle). The classification performance of the CNN ensembles on the test cohort is shown in terms of multi-class accuracy (ACC) and confusion matrices (bottom). Investigated scenarios include range prediction errors (µPE), setup errors in beam direction (µD), anatomical changes (ΔA), combination of these errors (ΔE) as well as non-relevant changes (NR).
Proton dose calculations based on fluence-modulated proton CT scans optimised for patient-specific dose and variance objectives

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Introduction
Proton CT (pCT) yields volumetric maps of the patient’s stopping power relative to water (RSP) for particle therapy treatment planning with errors below 1%. By dynamically modulating the proton imaging fluence, fluence-modulated pCT (FMpCT) images can be acquired with low image noise inside a region-of-interest (ROI, i.e. the treatment beam) and low imaging dose elsewhere.

Materials & Methods
We present an optimization algorithm for FMpCT that employs forward models for image variance and imaging dose implemented using sparse matrix multiplications, and evaluate it using an experimentally validated pCT Monte Carlo simulation. With a spatially non-uniform weighting, the doses at imaging organs-at-risk (OAR, e.g. eyes) were further reduced. FMpCT plans were optimized for three pediatric patients with tumors in the head where the ROI was defined as the 10%-isodose-line. Treatment doses were optimized on a RSP ground truth and recalculated based on uniform fluence pCT scans and modulated FMpCT scans with a research treatment planning system.

Results
FMpCT imaging dose was on average at 0.3mGy and reduced compared to uniform fluence by 74% outside of the ROI as shown in figure 1 for one patient. Doses in imaging OARs were reduced by up to 87%. The recalculated treatment dose in figure 2 agreed well, despite the elevated out-of-ROI noise level in the FMpCT scan in (c). The dose passing rate with a strict 1%-criterion was above 98% for FMpCT versus ground truth.

Summary
Patient-specific FMpCT imaging plans were optimized and tested in a simulation study demonstrating considerable dose reductions at a comparable dose calculation accuracy. Acknowledgment: DFG

Appendix

Figure 1: Imaging doses for (a) uniform fluence pCT, (b) FMpCT, and (c) imaging dose-volume histograms. Dose scale: mGy.
Figure 2: Treatment dose (a) based on ground truth RSP and recalculated on (b) pCT and (c) FMpCT, (d) dose-volume-histograms. Dose scale: percentage prescription.
Introduction
The standard method to determine the radiation risk of an x-ray examination is the calculation using conversion factors based on standard patient data [1]. This study provides individualized risk determination conversion factors for digital anthropomorphic phantoms with different BMI by Monte Carlo simulations.

Materials & Methods
An abdomen a.p.-radiograph was simulated for 14 XCAT-phantoms [2] with the CT simulation software GMctdoss [3] using the current tissue weighting factor from the ICRP-103 [4]. The eligibility of the BMI for risk assessment the detector doses in relation to the BMI and the water equivalent diameter was examined.

Results
The conversion factors for the colon, stomach and gallbladder decrease with increasing BMI (Figure 1). In addition, the effective body dose for radiographs with constant detector dose is compared for different BMI (Figure 2) which corresponds to the clinical situation.

Summary
This method offers the possibility to determine conversion factors for the BMI for different regions, field settings and tube voltages. Thus, conversion factors can be individually adjusted according to the latest recommendations of the International Commission on Radiological Protection ICRP-103. This allows the radiation risk to be determined individually, based on factors that are easy to obtain regardless of the uncertainties the BMI offers.

Figure 1: Conversion factors
Figure 2: Effective body dose

References


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V14  Cone Beam CT preset optimisation – low diagnostic dose AND high image quality

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Introduction
Daily image guidance has led to a reduction of stochastic positioning errors in radiotherapy. However, the daily diagnostic dose has to be as low as reasonably achievable, demanding for an optimized imaging system. Mandatory part of this system is quality assurance (QA), with checks to be performed routinely, quantitatively and as effectively as possible.

Materials & Methods
Different approaches to preset optimization are possible, e.g. reducing the current-time product in vendor provided presets until the relevant information is lost [1]. It is, however also possible to augmenting and optimizing presets for specific applications. This allows to factor geometry and reconstruction algorithms into dosimetric considerations.
Quality assurance is carried out in accordance with ÖNORM S 5290-3 using a CATPHAN-Phantom („The Phantom Laboratory“).

Results
A routine check with only one designated test preset is not sufficient, giving need to high QA-efficiency. Counting line pairs to determine the high contrast resolution is time consuming and subjective. A more objective approach is to consider the relative position of Gauss curves fitted to the grey values perpendicular to the lines. Implementing an automated evaluation of the Modular Transfer Function (MTF) of a bead or point source is a valid alternative.
Examination of the noise-spectrum in different directions allows identifying gradients or periodicities in the noise. This might reveal the sources of disturbances, making it superior to comparison of four peripheral regions with a central one.

Summary
In accordance with radiation protection, it is sensible to have a broad range of specific presets. Implementing CBCT routine checks into an integrated QA management software package capable of communicating with the Linac allows for routine, quantitative and very effective checks.

References
Introduction
Dose reduction and optimization are common measures performed for conventional CT scanners with the aim to reduce the patient dose as low as reasonably achievable while maintaining high image quality necessary for accurate clinical diagnostics. In cone beam CT (CBCT) imaging employed for localization in radiation therapy image quality must be sufficient to ensure registration accuracy between CBCT and planning CT. In this work optimization procedures have been carried out for different clinical CBCT protocols.

Materials & Methods
Measurements were done with a CT ionization chamber type 30009 with a NOMEX Dosemeter in a CTDI phantom type T40027 (all PTW Freiburg, Germany) using the on-board Elekta XVI CBCT of an Elekta Synergy linac (Crawley, UK). The standard presets (Pelvis M20, Chest M20 and Fast Head and Neck S20) were modified by lowering their mA and ms values and the resulting changes in CTDI air were measured free-in-air at the isocenter. Additionally, the CTDI w was measured for five CBCT presets to derive the conversion factors between CTDI air and CTDI w. The registration accuracy of all preset variations was assessed using the anthropomorphic ATOM 702 body phantom and the anthropomorphic STEEV head phantom (CIRS inc., Norfolk, VA, US).

Results
Reduction in mA and ms leads to a reduction of dose by up to a factor of four. The conversion factors between CTDI w and CTDI air differ approximately by 3 % for scans with the same voltage. The maximum discrepancy for all registrations was 0.3 mm in vertical direction for the head and neck preset and 0.2 mm in lateral and vertical direction for the Pelvis and Chest presets.

Summary
A reduction in CBCT imaging dose is possible without significantly reducing the registration accuracy of the imaging system. CTDI air measurements yielded good estimates for CTDI w values by applying the appropriate conversion factors.
Physiologically-based pharmacokinetic modeling of in vivo alpha generators targeting neuroendocrine tumours in mice.

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Introduction
Alpha emitter-based peptide receptor radionuclide therapy (α-PRTT) is an effective treatment for metastatic inoperable neuroendocrine tumors (NETs). Conjugated $^{212}\text{Pb}$ is considered as a promising in vivo generator of alpha particles through its alpha emitting daughter $^{212}\text{Bi}$. Investigating the fate of redistributed radioactive daughters in the body is essential to assess the efficacy and safety of α-PRTT. Mathematical modelling allows for performing animal-free experiments to study the pharmacokinetics of in vivo alpha generators targeting the somatostatin receptor type 2 (sstr2). A physiologically-based pharmacokinetic (PBPK) model was developed to describe the pharmacokinetics and dosimetry of alpha generators and their radioactive products in mice.

Materials & Methods
A whole-body $^{212}\text{Pb}$-PBPK model of alpha generators in mice was implemented in modeling software SAAM II (version 2.3) and Simbiology/MATLAB (MATLAB R2020a). The $^{212}\text{Pb}$-PBPK model describes all relevant physiological mechanisms and physicochemical properties of the generator systems with parameter values from the literature. The pharmacokinetic parameters in the $^{212}\text{Pb}$-PBPK model were estimated in both software using $^{212}\text{Pb}$-DOTAMTATE biokinetic data in xenografted mice after intravenous administration of 0.0013 nmol (146 MBq/nmol) [1]. Dosimetry calculations were performed in Simbiology after integrating a $^{212}\text{Bi}$-PBPK model into the $^{212}\text{Pb}$-PBPK model.

Results
The developed model successfully describes the experimental data. The fitted curves were good by visual inspection. The tumor plasma flow-rate was (0.33±0.45) ml/min/g. sstr2 densities in tumor, kidneys, liver, pancreas, spleen and lung were (5.94±1.04), (3.04±0.31), (0.13±0.03), (4.05±1.48), (0.57±0.04), (1.39±0.05) nmol/l, with absorbed dose coefficients of 0.23, 0.14, 0.86, 0.10, 0.03, and 0.07 Gy/kBq, respectively.

Summary
The developed $^{212}\text{Pb}$-PBPK model allows for simulating the biokinetics of in vivo alpha particle generators targeting sstr2. The $^{212}\text{Pb}$-PBPK model can address concerns about the fate of the distributed free radioactive daughters and their contribution to the overall absorbed dose to non-target tissues.

References (if applicable)
Investigating nonlinear mixed effect and physiologically-based pharmacokinetic modelling for simplified dosimetry in radiopeptide therapy

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Introduction
Time-integrated activity coefficients (TIACs) largely determine the absorbed doses in molecular radiotherapy [1]. The aim was to study the accuracy of a nonlinear mixed effect (NLME) and a physiologically-based pharmacokinetic (PBPK) model with one planar measurement to calculate the TIACs of $^{111}$In-DOTATATE measurements for dosimetry in peptide-receptor radionuclide therapy (PRRT).

Materials & Methods
A published whole-body PBPK model developed for treatment planning in PRRT was used. Biokinetic data of tumours, kidneys, liver, spleen and whole body (5 time points) and serum (8 time points) were obtained using planar imaging from eight patients after $^{111}$In-DOTATATE injection. An NLME model and the PBPK model with a single biokinetic datum at different time points were used to calculate the TIACs in the organs. The results were compared to the all-time-points fit as reference. The time point with the lowest relative deviation of the calculated TIACs to the true TIACs derived from patient P1 were used for calculating TIACs in the other 4 patients.

Results
Calculated TIACs using biokinetic data at 2 d p.i. in P1 showed the lowest relative deviations. Therefore, biokinetic data at 2 d p.i. were used to calculate the TIACs in the organs of patients P2, P3, P4 and P5. The median and the range of the relative deviations of the calculated TIACs to the true TIACs from five patients were 4.4 % [0.9-15.6] %, 4.1 % [2.4-13.3] %, 3.6 % [2.1-7.7] %, 7.9 % [0.2-12.5] %, 2.0 % [1.4-15.0] % and 4.3 % [2.5-15.1] % in tumours, kidneys, liver, spleen whole body and serum, respectively.

Summary
These results suggest one planar measurement might be used to calculate the TIACs of the OARs and tumours in PRRT using NLME and PBPK model with relative deviations around 10 %.

References
Population-based determination of time-integrated activity coefficients in molecular radiotherapy

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Introduction
The accuracy of the calculated time-integrated activity coefficients (TIACs) in molecular radiotherapy depends on the chosen fit function. Selection of an adequate model function is therefore of high importance. However, model selection [1] works more accurate with more (biokinetic) data than are usually available for an individual patient. The aim of this study was therefore to develop an algorithm for identifying the model/function most supported by the data of a patient population which might be used for determination of the time-integrated activity coefficients.

Materials & Methods
Kidneys biokinetic data of ¹⁷⁷Lu-PSMA obtained in thirteen patients with metastatic prostate cancer obtained from planar imaging were used in this study. In total, twenty exponential functions with various parameterizations of mono- \((A_1 e^{-(\lambda_1 + \lambda_{phys})t})\) and bi-exponential functions \((A_1 e^{-(\lambda_1 + \lambda_{phys})t} + A_2 e^{-(\lambda_{phys})t})\) were analyzed. The parameters of the functions with different combinations of shared and individual parameters were fitted population-wise simultaneously to the biokinetic data of all patients. The goodness of the fits were used to test the quality of the fits and the best function was selected based on the lowest corrected Akaike Information Criterion (AICc) value and the highest Akaike weights.

Results
The bi-exponential function \(A_1 b e^{-(\lambda_1 + \lambda_{phys})t} + A_1 (1 - b) e^{-(\lambda_{phys})t}\) with shared parameter \(b\) was fitted with an adequate goodness of fit and was selected as the best function based on the Akaike weight of 97 %. In this bi-exponential function, the \(A_1\) and \(\lambda_1\) parameters were fitted individually while parameter \(b\) was fitted as a shared parameter in the population with an estimated value of \((0.963±0.004)\).

Summary
An algorithm to define an adequate fit function was developed which is population-based and therefore can be used for future patients even for the case of a relatively small number of data per patient.

References
Diseases of the respiratory system are leading global causes of chronic morbidity and mortality. While advanced medical imaging technologies of today deliver detailed diagnostic information, a low-dose, fast, and inexpensive option for early detection and/or follow-ups is still lacking. Here, we report on the main principles and the key development milestones of the first human application of a novel modality, namely X-ray dark-field chest imaging, which might fill this gap. Enabling the assessment of microstructural changes in lung parenchyma, this technique presents a more sensitive alternative to conventional chest X-rays, and yet requires only a fraction of the dose applied in computed tomography (CT).

For this first clinical evaluation, we have built a novel dark-field chest X-ray system, which is also capable of simultaneously acquiring a conventional thorax radiograph. With this first system worldwide, we are presently conducting two patient studies. The first is devoted to chronic obstructive pulmonary disease (COPD), the second to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).

First results look very promising and show that X-ray dark-field chest imaging allows the diagnosis of COPD and COVID-19 more effectively than conventional chest X-ray does.

References
F5  X-ray Dark-Field Chest Radiography – Detection and Diagnosis of Pulmonary Emphysema in COPD-Patients

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Introduction
According to the World Health Organization, chronic obstructive pulmonary disease (COPD) is the third leading cause of death worldwide[1]. Pulmonary emphysema, one component of COPD, is characterized by permanent enlargement and destruction of the alveoli, the gas-exchanging entities of the lung. An early detection of the disease is crucial for a positive treatment response as there are currently only disease-delaying but no -modifying options available[2]. At the same time, COPD and emphysema are reported to be highly unrecognized conditions [3]. X-ray dark-field imaging is a novel imaging technique, which generates contrast based on coherent small-angle scattering at microscopic interfaces[4]. The technique has shown to be very sensitive to emphysema-induced structural lung changes in a small-animal disease model[5] and was recently transferred to a first application in humans at our institution. Here, we present a clinical study investigating the diagnostic capabilities of X-ray dark-field imaging with respect to the detection and staging of emphysema[6].

Materials & Methods
The study was approved by the institutional review board. A collective of 77 subjects was included. Subjects gave written informed consent. In the study protocol, X-ray dark-field and computed tomography (CT) images of the chest were acquired and visually assessed in a reader study by 5 radiologists. In addition, pulmonary function and clinical symptoms were recorded for every patient. The individual data sets were evaluated in a statistical work-up using the findings from the visual CT assessment as reference standard. Key specifications of our prototype system: Simultaneous acquisition of dark-field and conventional images, field of view: 37x37 cm² (patient plane), acquisition time: 7 seconds, effective radiation dose: 0.035 mSv (male reference person: 173cm, 73 kg).

Results
Emphysema assessment based on dark-field radiographs and CT-images yield consistent diagnostic findings. Markers extracted from the dark-field images show improved diagnostic performance in comparison to conventional clinical tests characterizing emphysema and yield a good correlation to the lung’s diffusion capacity (signal strength vs DLCO SB: ρ=0.62, p<0.0001).

Summary
X-ray dark-field chest imaging provides diagnostically relevant information on emphysematous lung impairment in humans. With approximately 2 % of the effective dose that is applied in a low-dose CT-scan, at some point dark-field radiography might be used as broadly deployed screening tool and by that help resolving the prevalent situation of underdiagnosed COPD.
References


F6  Determination of Dose Parameters

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Introduction
Dark-field radiography has already shown great potential for facilitated early detection of pulmonary diseases in different animal models and its capability to detect and quantify emphysema in human subjects. Currently, we are evaluating the benefit of dark-field radiography for imaged-based detection of emphysema in COPD and COVID-19 associated lung changes with a first clinical prototype system. To guarantee a diagnostic image quality for any patient collective, a given detector dose has to be obtained for each patient. Here we report on the determination of patient specific exposure parameters.

Materials & Methods
In the COPD study, we use a conventional radiograph with automatic exposure control to adapt the tube current for each patient individually. To this end, we determine an equivalent absorber thickness of the patient from the exposure settings at the conventional system, which is in turn converted to the required tube current at the dark-field system. Based on Pearson correlation coefficients between patients' body parameters and tube current, we chose the BMI for setting the tube current in the COVID-19 study, where there is no X-ray taken at a conventional system.

Results
By adjusting the tube current for each patient in the COPD study according to our calibration curve, we achieve detector dose values consistent with the target value. Further, the strong correlation between BMI and required tube current ($r = 0.87, p < 10^{-29}$) is utilized for tube current adaption in the COVID-19 study. There, we obtain a greater range in resulting detector doses.

Summary
The adaption of the tube current according to parameters from the automatic exposure control of a conventional system delivers consistent results. Without the additional conventional radiograph, a BMI-based adaption of tube current also results in dark-field images with diagnostic image quality.
Introduction

X-ray dark-field imaging is a novel imaging technique that allows for the visualization of the alveolar structure in the lung. Here, we evaluate how dark-field chest radiography can improve conventional chest radiography for the detection of COVID-19 induced changes in the lung.

Materials & Methods

Patients with COVID-19-associated lung changes in a CT scan as determined by the CO-RADS assessment scheme and a control group of patients without pathologic lung changes visible in the CT scan were included. The study was approved by the institutional review board and the national radiation protection agency. All patients gave written informed consent. We employed a clinical setup for grating-based X-ray dark-field imaging for the acquisition of chest radiographs. At an effective patient dose of 35 µSv for one examination of the reference person in posterior-anterior orientation, both a novel dark-field and a conventional attenuation image were obtained. Attenuation images alone, dark-field images alone, and both modalities combined were assessed for the presence of COVID-19-associated lung changes on a scale from 1 to 6 (1 = surely not, 6 = surely) by four radiologists. Statistical analysis was performed with a one-sided Mann-Whitney U test with a 0.05 level of significance. The effect sizes are given as the area under the receiver operating characteristic curve (AUC).

Results

A total of 100 patients (57±15 years, 56 male) were included, of which 40 were in the control group. Compared to dark-field images in healthy subjects, those of patients with typical COVID-19-associated lung changes in the CT scan showed an overall signal decrease. While the rating values for COVID-19 patients were highest for the combination of both modalities (p<0.05), ratings were also significantly higher for dark-field compared to attenuation-based imaging (p<0.001). AUC values were 0.78 (attenuation), 0.91 (dark-field), and 0.93 (dark-field & attenuation), respectively.

Summary

Dark-field imaging complements and improves conventional radiography for the visualization and detection of COVID-19 induced lung changes.
Appendix 1

Figure: Exemplary dark-field (A, B, C) and attenuation (D, E, F) chest radiographs of a healthy subject (A, D) and two subjects with COVID-19-associated changes in the lung. Same window levels were applied within each modality. As the dark-field signal is sensitive to the alveolar structure, it decreases when the lung is altered by COVID-19. Statistical analysis of the reader study is shown in (G). Significance levels are indicated by asterisks: *, p<0.05; **, p<0.01, ***, p<0.001. Abbreviations: H, Healthy control group; C-19, Covid-19 patients; AUC, Area under the receiver operator characteristic curve.
F8 Quantitative Comparison to Computed Tomography

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Introduction
X-ray dark-field imaging can detect structural changes of the human lung. Currently, the applicability of dark-field radiography for diagnosing chronic obstructive pulmonary disease (COPD) and for diagnosing COVID-19 associated changes of lung tissue is investigated in clinical studies. While COPD destroys the lung alveoli, causing emphysema, COPD leads to alveoli filled with fluid. Here, a quantitative comparison between dark-field chest radiography and computed tomography (CT) is presented for both diseases.

Methods
Using a clinical prototype for dark-field chest X-rays, the thorax of 94 patients with different stages of emphysema and 60 patients diagnosed with CT imaging findings typical for a COVID-19 infection were imaged. For the quantitative dark-field coefficient, the lung’s dark-field signal was summed up and normalized by the patient’s lung volume. The quantitative CT-based analysis of emphysema was performed with the commercial software IntelliSpace Portal (Philips, Netherlands). There, volumes in the segmented lung with values below -950 HU (Hounsfield Units) were classified as emphysematous. For COVID-19 patients, lung voxels above -700 HU were interpreted as being affected by the disease. For visual comparison to posterior-anterior dark-field images, the segmented CT images were converted to a two-dimensional image.

Results
Quantitative CT-based lung analysis and dark-field images yield consistent results for both COPD and COVID-19. Lung tissue categorized as damaged in the quantitative CT-based evaluation exhibits a decreased dark-field signal. Evaluating the correlation between dark-field coefficient and emphysema index for 13 COPD patients with significant emphysema index (>6%) yields a Spearman correlation of \( r = -0.79 \) (p<0.01).

Summary
Comparing dark-field radiographs and CT images shows that dark-field images can be used to detect structural changes of lung tissue, while requiring only a fraction of the dose necessary for CT.
Improving accuracy of proton computed tomography with an empirical artefact correction method

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Introduction
Volumetric maps of the patient’s stopping power relative to water (RSP) used for particle therapy treatment planning can be generated using proton CT (pCT) with errors at or below 1%. The performance of current pCT prototype scanners is limited by image artifacts distorting the RSP accuracy and a suitable correction method is required.

Materials & Methods
We present an empirical artifact correction for pCT which is based on a scan of a custom-made monolithic elliptical phantom. It makes use of radial basis functions to establish a WEPL-to-WEPL correction function. Its coefficients are found such that the corrected scan of the ellipse phantom is flat by optimization utilizing the linearity of the filtered backprojection operator. The correction function is then applied to projection values of subsequent scans. The method was applied to dedicated experimental data acquired with a prototype pCT scanner with four phantoms and at two incident energies in a single session.

Results
Application of the correction method considerably reduces image artifacts in the pediatric head phantom shown in figure 1 (compare left to center column). The soft tissue part of the phantom is made of only one material and a constant RSP is expected. The difference maps in the last column show a maximum error amplitude of about 2%. The mean average error of a known-RSP phantom (not shown) was reduced from 0.87 % down to 0.46 %. Scans of a homogeneous water phantom were considerably flatter.

Summary
Image artifacts of a pCT scanner could be considerably reduced using an empirical method as demonstrated on homogeneous and anthropomorphic phantoms. The accuracy of RSP values was improved by 47 %.
Acknowledgment: DFG
Appendix

Figure 1: Scans of a head phantom (a,d) without and (b,e) with correction, and (c) difference maps. Data acquired at 200MeV (first row) and 187.5MeV (second row).
V20 Quality assurance of interstitial brachytherapy for breast cancer with a novel, mobile CBCT system

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Introduction
In interstitial brachytherapy of breast cancer, control of in-situ implant geometry during therapy is one component for validating a correct dose distribution within the affected tissue. Essential for this is appropriate volumetric imaging, e.g. using cone-beam computed tomography (CBCT). The work’s scope is to present a corresponding treatment workflow using a novel, mobile CBCT-system.

Materials & Methods
The focus was on breast cancer patients receiving HDR-brachytherapy alone (9x3.8 Gy) as accelerated partial breast irradiation (APBI). Treatment planning is based on CT-scans with implanted flexible plastic catheters in-situ, acquired with a conventional CT-system. Following the 4th fraction of APBI, a control-CBCT is performed directly in irradiation room with a novel, mobile CBCT-system with wireless remote control via tablet-PC. Motorized wheels allow translations as well as rotations of the device, enabling it to move over the patient couch for imaging in treatment position. Based on the CBCT-scan the treatment plan’s validity is checked and, if required, treatment adaption is conducted. Our site deployed the novel system worldwide first for brachytherapy in 02/2021. Four patients were treated with this workflow so far.

Results
With the novel CBCT-system, a smooth workflow was achieved. The image quality of the device was sufficient for potential re-planning of dose distribution for three patients at low dose (CBDIw < 5 mGy), due to the low-contrast differentiability within the mamma and the high contrast between tissue and catheters suitable for catheter reconstruction (Fig.1). One patient could not be examined due to technical problems.

Summary
With the novel CBCT-system a smooth workflow for treatments of breast cancer was created. The device’s image quality was sufficient for clinical requirements at low dose.

Appendix 1

Fig. 1: Mamma scan acquired with the novel CBCT-system. The implanted catheters were distinctly demarcated from tissue. Low-contrast structures (green arrows) were differentiable.
Commissioning and quality assurance of a novel image guidance system combining surface imaging and stereoscopic radiographic imaging

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Introduction
Recently, novel image guidance technology with combined floor-mounted stereoscopic X-ray imaging and surface imaging was introduced commercially, i.e. the Exactrac Dynamic (ETD) system (Brainlab). The optical surface camera is augmented by a thermal camera. This work describes the comprehensive commissioning and quality assurance (QA) of the ETD system.

Materials & Methods
During commissioning the field-of-view, surface drift, consistency between X-ray and surface positioning, static and dynamic localization accuracy, beam-hold mechanism (dosimetrically and geometrically) and temperature dependency were determined. Contrast-to-noise ratio, spatial resolution, geometric accuracy, dose and exposure linearity were measured for the X-ray system. A moveable phantom consisting of a torso made of thermoplastic material with programmable breathing motion patterns was employed. The phantom features steel spheres as hidden targets for registration, a static ion chamber holder and a heating mechanism.

Results
Static localization accuracy w.r.t. the linac isocenter was determined to be <1 mm for both the X-ray and the surface scanning system and was stable over 5 months. Radiographic and surface positioning was consistent with maximum errors of 0.5 mm and 0.5\degree without a temperature gradient. During the first 60 minutes after power-on of the surface scanner, a drift of 1.3 mm of the surface was observed. After that a reproducibility of ±0.2 mm was reached. Surface-of-interest definition turned out to be very crucial and influenced the stability of the surface signal with respect to time and temperature. Dosimetric reproducibility with surface guided beam on/off functionality was proven by the movable phantom. Current QA tests based in the initial experience and their frequencies are summarized in Table 1.

Summary
The ETD is an accurate hybrid radiographic and surface image guidance system after proper warm-up. The integrated processing of anatomical and surface images in the same software merges the fields of image guided and surface guided radiotherapy.

Appendix 1
Figure 1: Heated motion phantom monitored by the ETD system

### Appendix 2

#### Localization stability
- Daily: Thermal-to-surface calibration
- Monthly: X-ray image quality
- Half yearly: End-to-end test
- Yearly: Surface scanner stability

#### Consistency X-ray-surface
- Daily: Localization accuracy of ETD to CBCT
- Monthly: X-ray dose
- Half yearly: Surface scanner stability
- Yearly: Extensive localization

#### Dynamic localization accuracy
- Daily: Localization accuracy to linac isocenter
- Monthly: Surface scanner stability
- Half yearly: Extensive localization
- Yearly: Surface scanner stability

#### Beam-hold mechanism
- Daily: X-ray-surface localization
- Monthly: Localization accuracy to linac isocenter
- Half yearly: Extensive localization
- Yearly: Surface scanner stability

### Table 1: Current QA tests and their frequencies
Clinical evaluation of an intelligent 4DCT algorithm and scanning mode

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Introduction
Commercially used 4DCT algorithms often lead to artifacts, as respiratory irregularities during data acquisition can result in insufficient coverage of the projection data. The intelligent 4DCT (i4DCT) algorithm and scanning mode automatically adapts CT data acquisition to the patient’s breathing pattern using online analysis. Clinical data concerning image quality, beam-on time (as a proxy of dose) and projection data will be evaluated.

Materials & Methods
Data from 129 breathing curves from patients with thoracic tumors were included in the analysis. Additionally, a subgroup of 30 challenging breathing curves was defined. Projection data coverage and beam-on time was evaluated for both groups. Image quality was analyzed with a rater study performed by ten clinical experts for the challenging cases.

Results
Qualitative results achieved by the rater study revealed that 78 % and 63 % of these 30 challenging cases (amplitude- and phase-based, respectively) had no or only minimal artifacts (see figure 1). Only 2 % and 9 % (amplitude-based, phase-based, respectively) had strong artifacts leading to a total loss of relevant image information. The average beam-on time per couch position was 4.92 ± 1.64 s for the entire patient cohort and 5.07 ± 1.72 s for the challenging cases, respectively. A significant difference could not be proven (p=0.64). For the entire cohort, the median projection data coverage was 93.4 % and 94.0 % (inhalation and exhalation, respectively). Results of 89.7 % and 92.7 % for inhalation and exhalation, respectively, were achieved by the subgroup.

Summary
Due to the patient-specific adaptation of the scan parameters and the automatic adaptation of the beam-on periods by online analysis, i4DCT achieves very good results for clinical application in thoracic tumors, even for patients with very challenging breathing patterns.

Figure 1: Summary of the expert rater study results. Relative incidence is visualized for the different reconstruction modes as well as expert groups.
Joint Conference of the ÖGMP, DGMP and SGSMP

V23 Finalisation and performance evaluation of a novel PET detector for an in-beam small animal PET scanner

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Introduction
We have designed a unique spherical in-beam PET scanner for a novel small animal proton irradiator under development in our group (Fig. 1 (a)). This in-beam PET scanner will image positron emitters generated by the proton beam. In this study, we finalized the configuration of the PET detector and evaluated its performance.

Materials & Methods
Fig. 1 (b) shows the in-beam PET detector composed of a pixelated 3-layer LYSO scintillator block and an 8×8 MPPC array (Hamamatsu photonics K.K, S14161-3050HS-08). The scintillator pixel size is 0.9 mm×0.9 mm×6.67 mm. The array size of the 1st, 2nd and 3rd layers are 23×20, 23×23 and 24×24, respectively. A charge division circuit (CDC) is used to reduce 64 signals to 4 signals. Those signals are transferred to an amplifier circuit board and converted from single-ended to differential readout, connected to a R5560 (CAEN) digitizer module. An Anger calculation is used to identify the interaction position [1]. We configured one pair of the PET detector setup and used a Na-22 point source to reconstruct the corresponding image using a maximum likelihood estimation algorithm.

Results
The point source image was symmetric along x and y directions (Fig. 2 (a)). The Full-Width-at-Half-Maximum of a line profile was 0.85 mm (Fig.2 (b)).

Summary
We finalized and evaluated the in-beam PET detector for our novel small animal in-beam PET scanner. We expect that sub-millimeter spatial resolution will be achievable for the entire system.

Figure 1
Fig.1: (a) Design of the novel small animal in-beam PET scanner and (b) a staggered 3-layer PET detector module.

Figure 2
Fig.2: (a) Reconstructed image of the point source and (b) line profile of the image.

References
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Joint Conference of the ÖGMP, DGMP and SGSMP

V24 Estimating CTs using electromagnetic tracking (EMT) - detection and visualisation of interfractional changes of the catheter implant in interstitial brachytherapy (iBT) of the breast

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Introduction
Interfractional changes of the catheter implant during HDR iBT for patients with mammary carcinoma are not assessed systematically in clinical routine. Due to this, a proportion of ~4% of patients received suboptimal treatment [1]. We have developed an algorithm to estimate a CT (ECT) by combining the data from the planning CT (PCT) and from measurements with a dose-free EMT system after each fraction [2]. Thus, we are able to estimate and visualise interfractional changes of the implant geometry at any time during the treatment.

Materials & Methods
EMT data were recorded with an afterloader prototype equipped with an EMT sensor. EMT implant reconstructions were acquired immediately after the PCT (EMTPCT), follow-up CT, and every fraction of the treatment and each used to calculate a deformation vector field with respect to EMTPCT. The deformation field was subsequently applied to the PCT, resulting in a warped ECT. To validate the estimation, the ECT was compared to the rigidly registered FCT (rFCT) in terms of HU differences in the planning target volume (PTV) and in a convex hull (CH) around the catheters.

Results
The HU difference (mean±STD) between ECT and rFCT over all patients is 45±82 HU for the PTV and 84±217 HU for the CH. These results are comparable to the differences between PCT and rFCT. The CT estimation method is automated, scriptable and currently applied to >70 patients totalling >600 treatment fractions. Exemplary image data of one patient are shown in Fig. 1. Additional dosimetric evaluation is ongoing.

Summary
The presented approach for CT estimation was successfully validated. Thus, insights can be gained into the temporal development of interfractional changes. Our aim is to analyse the effects on dose distribution and derive the most meaningful time for a clinical FCT.

<table>
<thead>
<tr>
<th>PCT</th>
<th>ECT Fx2</th>
<th>ECT Fx4</th>
<th>ECT Fx7</th>
<th>ECT Fx9</th>
</tr>
</thead>
<tbody>
<tr>
<td>t = 0 h</td>
<td>t = 21 h</td>
<td>t = 46 h</td>
<td>t = 76 h</td>
<td>t = 98 h</td>
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</tbody>
</table>

Fig. 1. Exemplary image data computed using the CT estimation algorithm showing estimated development of interfractional changes during the course of treatment.

References
Session 8 I Free Topics 1

V25 Requirements for the implementation of a process control framework to improve treatment plan quality

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Introduction
Plan quality (PQ) is usually assessed by the examination of the dose distribution. With the aim to simplify the planning process/decisions a process control framework was outlined and its feasibility to detect poor quality plans was evaluated.

Materials & Methods
Parameters that might influence the PQ along the radiotherapy workflow were found with help of a flow diagram (Fig.1). 105 bronchial cancer patients with normo-fractionated VMAT-plans were selected for the pilot-dataset. The center line (CL), upper control limits (UCL), lower control limit (LCL) and capability indices were calculated as in [1] for the following parameters: i) PMU (plan normalized monitor unit used to predict the degree of plan modulation[2]); ii-a) dose difference and Gamma-index of an independent dose verification Software (iD.QA) and ii-b) a patient specific plan verification (Pat.QA). The plotted histograms of the data were used to estimate the data distribution. The plans outside the control limits were further examined with different PQ-metrics (Tab.1).

Results
The PMU data approximately follows a normal distribution (fig.2a). The target volume of the two plans outside the control-limits in fig.2b, consist of lung volumes extending into the spine with a sweep dose gradient towards spinal cord, leading to a higher beam modulation. Tab.1 shows the PQ of Plan 62 is poor. The coverage of plan 40 is poor, but the HI and CI are acceptable. The process control for the Gamma-Index of the Pat.QA indicates only Plan 62 to be out of control. Regarding dose-difference and gamma-index of the iD.QA both cases were in control.

Conclusion
The potential to use the process control framework outlined in this work to indicate poor plan quality is high. Other parameters in fig. 1 are evaluated with the same process, to check if there is a more suitable parameter to predict the plan quality. Correlation-Analysis between the different parameters and the plan quality metrics will be evaluated, as well the TPS-integration.

Table 1: Plan quality metrics for the two plans outside the PMU control limits. ($D_{min} =$ min. surrounding dose (D); $R_{ref}$= ref. Isodose (95% of prescribed dose ($D_{p}$)); $D_{V5\%-95\%}$= Dose at 5\% & 95\% volume ($V$); $TV_{ref}$ = target Volume ($TV$) and $V_R$= total V. covered by $RI$). The HI-limits is from [4] and CI-limit from [5]. Result within limit is considered as acceptable (green) and outside limit as poor (red).

<table>
<thead>
<tr>
<th>Plan quality metrics</th>
<th>Equation</th>
<th>Limit</th>
<th>Plan 40</th>
<th>Plan 62</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of coverage (Q)</td>
<td>$Q_{RTDOG} = \frac{D_{min}}{RI}$</td>
<td>$Q &gt; 0.95$</td>
<td>0.92</td>
<td>0.70</td>
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<tr>
<td>Homogeneity Index (HI)</td>
<td>$HI = \frac{D_{V5%-95%}}{D_p}$</td>
<td>$HI &lt; 0.15$</td>
<td>0.12</td>
<td>0.23</td>
</tr>
<tr>
<td>Conformity Index (CI)</td>
<td>$CI_{paddock} = \frac{TV_{R}}{TV \cdot V_R}$</td>
<td>$CI &gt; 0.85$</td>
<td>0.87</td>
<td>0.69</td>
</tr>
</tbody>
</table>
Figure 1: Various parameters that could influence the plan quality (orange) the radiotherapy workflow (blue). The yellow outlined parameters were evaluated in this study and the other parameters (gray) will be evaluated in the future.

Figure 2: Evaluation of PMU data. (a) Histogram and b) PMU statistical process control chart; (mean of data: $CL = \bar{X}$, Upper control limit: $(UCL = \bar{X} + (3 \cdot R/1.128))$ and lower control limit: $(LCL = \bar{X} - (3 \cdot R/1.128))$)

References
V26  Dose assessment in a voluntary patient after radon therapy

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Introduction
The radioactive noble gas radon contributes considerably to the annual radiation exposure and is classified as carcinogenic. In contrast, it is also used to treat inflammatory diseases (e.g. rheumatoid arthritis or ankylosing spondylitis). Studies suggest positive effects such as pain reduction and decreased inflammation, although the underlying biological mechanisms are widely unknown. At the same time, data on radon uptake and distribution throughout the body are scarce, making an accurate dose estimation and subsequent risk assessment for radon therapy complicated.

Materials & Methods
In a radon gallery a voluntary patient was exposed for one hour to radon activity concentrations between 27-77 kBq/m³ under constant filtration of radon progeny from ambient air. Afterwards, the short living radon decay products $^{214}$Pb and $^{214}$Bi were measured with a portable $\gamma$-detector at the abdominal and thoracic site for up to 24 hours. Considering the radon decay chain and geometrical properties of the measurement setup, the time-dependent activity curves were determined from which a dose estimation was made.

Results
The time course of the $^{214}$Pb and $^{214}$Bi activities is in agreement with theoretical models. At both measurement regions, most of the incorporated radon is removed in the first 3 hours, while a small fraction is retained considerably longer than the half-life of the decay products. This fraction accounts for over 80 % of the deposited energy released by incorporated radon gas. The obtained overall dose values are ~2-3 $\mu$Gy for a one-hour exposure at 100 kBq/m³.

Summary
Our measurement procedure allows to determine the applied dose to a patient in a most direct way by detecting decaying radon at distinct body sites. With these data a reliable risk assessment can be conducted which is independent from current uncertainty-prone, retrospective approaches. We thank BMBF (02NUK050A) and Acuradon (Bad Kreuznach).
Investigation on using the microSilicon detector for measurements around high dose rate 192Ir brachytherapy sources

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5University of Applied Sciences Giessen, Institute of Medical Physics and Radiation Protection, Gießen, Germany
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Introduction
Measurements in high dose rate (HDR) brachytherapy are challenging and require suitable detectors. We investigated the suitability of the microSilicon 60023 detector (PTW -Freiburg) to measure the radial dose function $g_L(r)$ and the anisotropy function $F(r, \theta)$ of a HDR 192Ir source.

Materials & Methods
The 192Ir source model v2r (Elekta) was placed in a MP3 water phantom (PTW -Freiburg). The microSilicon was employed to measure at distances $r$ from 0.5 to 10 cm and angles $\theta$ from 0 to 168°. The Monte Carlo (MC) toolkit EGSnrc was used to simulate the measurements and to determine energy dependence and volume-averaging correction factors. Subsequently, $g_L(r)$ and $F(r, \theta)$ were calculated from the detector reading corrected with the MC-based factors and were compared to the consensus data.

Results
The energy dependence correction ranged from -43 % ($r = 10$ cm) to +1.2% ($r = 0.5$ cm). The volume-averaging was up to -1.1 % for $r \leq 1$ cm and became negligible for larger distances. Good agreement was observed between measurements and simulations (average absolute difference 0.8 %, range from -3 to +2.4 %), as well as between measured and consensus $g_L(r)$ and $F(r, \theta)$ (average differences of 0.6 and 0.9 %, ranges from -2.2 to +0.6 % and -2.1 to +4 %, respectively) (Fig.1). Most differences were within the 2 % estimated uncertainty ($k = 1$). The largest difference (+4 %) was observed for $F(1\text{ cm},0^\circ)$.

Summary
The microSilicon is suitable for the determination and validation of the TG-43 parameters of 192Ir sources, provided that energy dependence and volume-averaging corrections are applied. The energy dependence had a considerable impact especially for larger distances because of the softening of the spectrum. The discrepancy observed for $F(1\text{ cm},0^\circ)$ may suggest a reconsideration of the $F(r, \theta)$ consensus data.
Figure 1: Measured vs consensus $g_l(r)$ (a) and $F(r,\theta)$ (b).
V28 Influence of α-particle radiation on intercellular communication networks of tunnelling nanotubes in U87 glioblastoma cells

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Introduction
The aggressive nature of glioblastoma, a common brain tumor, is composed of several features like uncontrolled cell-growth, high infiltration rates and their strong ability to develop therapy resistance. For their organization, an effective cell-to-cell communication among the cancerous cells is essential. One remarkable communication mechanism of cells are tunneling nanotubes (TNTs). These ultra-fine membrane connections with a diameter from 50 to 1500 nm enable cells to network very strongly with each other and thus ensure their survival. Here, we study the response of TNT communication networks in glioblastoma cells on radiative stress induced by α-particle radiation. The aim was to figure out whether cellular TNT-networks are influenced by radiation and if cellular communication is enhanced upon radiation treatment.

Materials & Methods
U87 glioblastoma cells were homogenously irradiated with high-LET α-particles to a dose of 1.2 Gy. After post-irradiation incubation times up to 72 h, the cell membrane was labeled and the TNT-network was examined using live-cell confocal microscopy. In our study, we suggest an evaluation method to characterize these communication networks and describe the development of TNT-networks after radiation treatment.

Results
Our results show that irradiated cells establish their network faster and have more cell-to-cell connections with a high TNT content than sham irradiated controls within the first 24 h.

Summary
These findings indicate that cancer cells respond with a fast and intensive TNT-network formation to radiation and the development of such a resistant communication network could be a responsible cellular mechanisms for therapy resistance.
V29  Measuring CT image quality using the relative transferred information

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Introduction
Although task-based image quality assessment using model observers is suitable for quality assurance of modern CT imaging, the workload of these methods is forbiddingly high for practical applications. Therefore, simpler methods are needed.

Materials & Methods
We have investigated the applicability of the relative transferred information (RTI) [1], which is defined as the mutual information between the object and its image divided by the information entropy of the input. We have applied it to images of the MITA body phantom for a typical abdomen protocol at a CTDI of 10-11 mGy for three different CTs with filtered back projection and iterative reconstruction methods. For the figure of merit, a weighted mean of the four values corresponding to four different contrast objects was used.

Results
Results for the RTI were compared to the signal-distance to noise ratio (SDNR) and to results from the recently developed model observer RDI [2]. The very strong linear correlation between SDNR and RTI reveals that also the SDNR is measuring the information passed through the imaging system. The correlation with the detectability \(d'\) obtained from the model observer is not as strong but still high.

Summary
The RTI information-theoretical approach provides a promising alternative for practical quality assurance of CT imaging. Results indicate that SNDR may still be a useful measure for image quality assessment of modern CTs.

![Figure 1: Figures of merit for CTs of three vendors, FBP and iterative reconstruction methods. Left: SDNR vs. RTI; Right: \(d'(RDI)\) vs. RTI.](image)

References
Introduction:
In modern treatment planning, feeding the optimization algorithm with the “correct” parameters may be challenging. Finding satisfying parameters can be a well-educated first guess or an odyssey. In clinically identical situations, optimization parameters for PTV coverage as well as OAR constraints depend on the patients’ anatomy and should be derived automatically from their respective anatomical proportions.

Materials & Methods:
A crystal report query selects all patients with a specific type of treatment and collects them in a database. Using Python, the programming language with which the RayStation (RaySearch) planning software can be controlled, the individual patients are investigated with respect to their anatomical proportions.
A gradient descent algorithm with polynomial regression and multiple variables calculates satisfying optimization parameters.

Results:
With the above mentioned method, prostate cancer treatment plans can be generated fully automated after assigning the target volumes, see fig. 1. The goal is to extend this method to other entities. Plans which receive a very good rating are fed into the database, which allows the algorithm to learn from its own creations.

Summary:
Automation of simple routine treatment plans like prostate plans saves time and lead to a good treatment quality. Additionally, the standardization simplifies the scientific evaluation.

Appendix 1

Figure 1: Template for prostate plans
Session 9 | Molecular Imaging

V31 Towards a $\gamma$-PET prototype – commissioning and first images in compton and PET mode

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$^2$KETEK GmbH, Munich, Germany
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$^4$National Institutes for Quantum and Radiological Science and Technology (QST), Chiba, Japan

Introduction
Combining a Compton camera (CC) and a PET scanner, the so-called $\gamma$-PET imaging modality, is capable of detecting triple-coincidences of two positron-annihilation photons and a higher-energetic $\gamma$-ray emitted by the daughter nucleus of the $\beta^+$-decay from radio-tracer isotopes like $^{44}$Sc or hadron-therapy products like $^{10}$C/$^{14}$O, resulting in a line-of-response and a Compton cone. This allows for determining the $\gamma$-emission centre from a single decay, resulting in a drastic sensitivity improvement compared to conventional PET.

Materials & Methods
Our prototype consists of two opposing 16×16 GAGG scintillator arrays (1.6 mm pitch) as PET arrangement and a single CC arm commissioned with a GAGG array (scatterer) ($\Delta E/E_{662keV} = 10.0 \%$) and a 16×17 (17×18) [18×18] three-layered LYSO array (1.4 mm pitch) (absorber) ($\Delta E/E_{662keV}$ (1st layer) = 12.8 \%) placed perpendicular to the PET detectors (all with SiPM readout). Compton and PET images were taken using a $^{22}$Na point source in a source-to-detector distance of 5 cm. For the CC, the system performance was furthermore evaluated at a source-to-scatterer distance of 1 cm.

Results
The source could be imaged in PET and CC configuration (2 mm accuracy). The spatial resolution (SR) obtained by the CC was found to be 3.6 mm at 1274 keV (at $z = 11$ mm). The angular resolution measure (ARM) and SR are summarized in Table 1.

Summary
Clear images of the point source could be obtained in the CC and the PET mode.
Supported by BFS, EU MSCA-IF, EU ERC and QST-NIRS
Appendix 1

![Figure 1: Compton images of a $^{22}\text{Na}$ source placed in a central/off-center position (top) at 511 keV and taken at two different source-to-scatterer distances (bottom) at 1274 keV. The dashed lines indicate the true source position.](image)

Appendix 2

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>511</th>
<th>511</th>
<th>511</th>
<th>1274</th>
<th>1274</th>
<th>1274</th>
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<td>(0, -1, 11)</td>
<td>(5, -5, 11)</td>
<td>(0, 0, 50)</td>
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<tr>
<td>Reconstructed (x,y) positions (mm)</td>
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<td>(0, 2)</td>
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<td>(3, -5)</td>
<td>(-1, -1)</td>
</tr>
<tr>
<td>ARM (deg)</td>
<td>14.9</td>
<td>14.0</td>
<td>11.0</td>
<td>15.7</td>
<td>13.1</td>
<td>8.2</td>
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<td>SR$_x$ (mm)</td>
<td>3.7</td>
<td>4.2</td>
<td>13.7</td>
<td>3.6</td>
<td>3.3</td>
<td>6.0</td>
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<tr>
<td>SR$_y$ (mm)</td>
<td>3.6</td>
<td>4.7</td>
<td>12.9</td>
<td>3.7</td>
<td>3.4</td>
<td>6.1</td>
</tr>
</tbody>
</table>

*Table 1: Reconstructed $^{22}\text{Na}$ source positions, ARM and SR (FWHM) of the CC measured for two $\gamma$-energies.*
Experimental comparison of particle and x-ray CT for particle therapy range prediction

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\textsuperscript{2}University College London, Department of Medical Physics and Biomedical Engineering, London, United Kingdom
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\textsuperscript{7}Loma Linda University, Basic Sciences, Division of Biomedical Engineering Sciences, Loma Linda, CA, United States
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\textsuperscript{9}Heidelberg University, Department of Physics and Astronomy, Heidelberg, Germany

Introduction
Particle CT promises improved relative stopping power (RSP) determination in particle therapy. However, given dual-energy x-ray CT (DECT) RSP accuracy, it is debated whether particle CT is needed for treatment planning. We present the first direct comparison of RSP and range prediction accuracy between DECT and particle CT in animal tissue.

Methods
Two phantoms containing fresh animal samples were built: 1) 16 homogeneous bovine/porcine tissues were filled into cylindrical containers and placed into a PMMA phantom (ø15cm) for CT scanning (Figure 1a). Reference RSPs were acquired by Peakfinder (PTW, Freiburg) measurements. 2) Heterogeneous cranial slices from a pig's head were placed inside a cylindrical phantom (ø15cm) and fixated with agarose-water gel (Figure 2a). A proton beam (84.67mm range) depth-dose measurement was acquired using a stack of Gafchromic\textsuperscript{TM} EBT-XD films in a central insert in the phantom. Proton (pCT) and helium ion CT (HeCT) were performed using the US pCT collaboration scanner at the Heidelberg Ion-Beam Therapy Center. DECT and single-energy x-ray CT (SECT) scans were done with a Somatom Definition Flash (Siemens, Forchheim) scanner and converted to RSP. The RSP accuracy of each modality was evaluated for the homogeneous tissue samples. For the pig's head, proton range estimates were simulated based on each modality scan.

Results
RSP accuracy of DECT was $(0.61\pm5.51)$ %, that of HeCT $(0.68\pm4.00)$ %. pCT achieved $(1.07\pm3.70)$ %, SECT $(2.06\pm5.02)$ % (Figure 1b). For the pig head, DECT, SECT, HeCT and pCT predicted range accuracy was 0.45%, 1.40 %, 0.25 % and 0.39 %, respectively (Figure 2c/d).

Summary
As clinically available method with good RSP accuracy, DECT is the currently recommended choice for particle treatment planning. Particle CT remains attractive for planning and treatment verification, but technical improvements are needed to reduce acquisition time and allow wider availability.
a) Tissue samples at the peakfinder (left), and inside the phantom (right)

b) RSP accuracy for SECT, DECT, HeCT and pCT for the tissue samples

Figure 1: RSP accuracy for homogeneous tissue samples

a) Construction of the pig-head phantom  

b) Finished phantom

c) Comparison of SECT, DECT, pCT and HeCT reconstructed RSP maps

c) Proton beam simulation on HeCT  

Figure 2: Pig-head phantom range evaluation.
Introduction
Magnetic Particle Imaging (MPI) has become a promising tomographic method for multiple applications. For medicine in particular it could become an applicable radiation-free option for endovascular interventions. As next step on the path of MPI into clinical practice, the hardware needs to be scaled up for human-sized applications, which is associated with several issues. In this abstract, a specifically designed human-sized MPI scanner is presented to meet the requirements for cardiovascular interventions such as PTA.

Materials & Methods
The aim of the interventional MPI scanner (iMPI) is to provide a radiation-free system comparable to the clinical gold-standard DSA. This requires good spatial resolution, high temporal resolution, near real-time visualization, and an open design that provides a comfortable and flexible environment for patients and medical staff. The open design allows for simultaneous conventional DSA.

To provide a sufficient magnetic field gradient, which is required for a high spatial resolution, a novel hardware approach is used to generate a field free line (FFL) within a specific ROI (Fig.1 left). By rapidly moving the FFL along specific trajectories through the ROI, the signal of the superparamagnetic tracer is used to calculate their spatial distribution resulting in projections comparable to DSA.

Results
To guarantee a strong magnetic field gradient, high amount of power is required resulting in a power dissipation of about 60 Kilowatts in continuous mode.
An alternative approach is a pulsed measurement mode, where a short sequence is generated to scan the ROI sequentially.

Summary
A first human-sized projection MPI scanner for interventional treatment of human-sized legs has been designed and built providing promising results to pave the way to clinical routine.
Evaluation for an intraoperative CBCT imaging system in combination with U/S-Imaging for prostate brachytherapy

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Introduction
The main issue in terms of the most accurate treatment planning in brachytherapy is the correct localisation of the applicators with high accuracy in combination with the related anatomy target volume(s) and organs at risk. In our current research scenario, we are investigating the value of a new imaging technique, in combination with transrectal ultrasound, for the HDR brachytherapy of prostate cancer.

Methods
It has been used a recently developed intraoperative CBCT system (Imaging Ring, medPhoton Austria) with a mechanical clearance of 121 cm which features a 43x43 cm² FPD and isocentric gantry with computer-controlled motorization of rotation (0–360°) and angulation (±30°). Geometric setup was assessed in terms of a lithotomic position for prostate brachytherapy using the brachytherapy type OR table and the immobilizer/stepper device. Further a dedicated set-up to simulate pelvic region with an embedded U/S-prostate phantom (CIRS 062MQA) and an intracavitary U/S biplane probe mounted on the stepper with implanted metallic needles has been considered. Various scanning protocols were evaluated, with variation of mAs and filtering per scan including custom choice of resolution size (0.07 mm voxel size) and multi scatter correction.

Results
The Imaging Ring provided a consistent platform for quantitative assessment of intraoperative imaging performance compatible with a broad spectrum of kV energies. The 120 kV image with a selection of small focal spot(0.3mm) and fullbow tie filtration mAs option showed an increase of soft tissue contrast-to-noise ratio compared to the large focal spot(0.6mm) settings of the system. The 120 kV CBCT image showed also reduced metal artefacts based on custom made reconstruction protocol.

Conclusion
Our results make us optimistic regarding the perspective of introducing the Imaging Ring in the clinic for intraoperative treatment planning process of prostate brachytherapy, particularly during the verification of the needles’ placement and their reconstruction especially with relation to anatomy.
Intrafractional optical surface/thermal imaging vs. X-ray monitoring for open mask cranial radiotherapy

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Introduction
Intrafractional motion during cranial radiation therapy could lead to significant deviations between planned and delivered dose. The ExacTrac Dynamic (Brainlab AG, Germany) allows continuous monitoring of the patient surface inside an open thermoplastic mask using combined surface/thermal imaging, while simultaneously relying on orthogonal X-rays to provide the position of bony anatomy structures. We evaluated the differences between the surface/thermal data of structures visible in the open-face mask and the corresponding X-ray bony anatomy registration during cranial radiotherapy (figure 1).

Materials & Methods
142 fractions of 14 patients (median age 59y) immobilized with an open-face mask were analysed. Intrafractional X-ray corrections for all six degrees of freedom were compared with the mean surface/thermal motion in all dimensions. X-rays were acquired for each treatment beam, at gantry positions 0°, 90°, 180°, and 270°. We evaluated mean, standard deviation, standard error of mean, and the 95% confidence interval of all 10 patient datasets.

Results
806 X-ray & surface/thermal imaging measurement pairs were analysed. Table 1 shows the small differences between X-ray corrections and surface/thermal imaging monitoring, which were in the sub-millimeter range for translations and below 0.5° for rotations and overall intrafractional X-ray deviations.

Summary
Very small differences were observed for this relatively small patient cohort. A further evaluation of these datasets and an extension to other treatment sites is planned. The data already suggest that for specific patient cases, the number of X-ray monitoring images could be reduced due to the stability and accuracy of the optical surface/thermal imaging algorithm.

Appendix 1

Figure 1: X-ray (left) and surface/thermal surveillance. ROI: open-face mask opening. The values in the center indicate the differences between the two modalities. Bottom: motion monitoring (green: surface, blue: X-ray).
Appendix 2

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>STD</th>
<th>SEM</th>
<th>95% CI</th>
<th>Mean</th>
<th>STD</th>
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<td><strong>Yaw (°)</strong></td>
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<td>-0.02</td>
<td>0.18</td>
<td>0.01</td>
<td>[-0.03 0.00]</td>
</tr>
</tbody>
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*Table 1: Left: Deviations between X-ray and optical surface/thermal imaging monitoring; right: X-ray monitoring values.*
Einleitung

Materialien & Methoden

Ergebnisse

Zusammenfassung
Zusammenfassend ermöglicht das Phantom anthropomorphe Kontraste und Organbewegungen von Leber und Nieren, welche multimodal dargestellt werden können. Dies bietet die Möglichkeit Qualitätssicherung an bereits bestehenden System zu verbessern, sowie Testungen neuentwickelter Systeme vorzunehmen.
Introduction
The purpose of this study is to set up a quality assurance check for in-room image data used for (online) adaptive proton therapy; specifically for intensity corrected cone beam CT (scCBCT) images. In addition to commonly used dose recalculation approaches, we measured proton ranges in a 3D printed phantom and explicitly accounted for the influence of the image information on the optimization.

Materials & Methods
Three brain patients were selected to focus on image intensities. For all patients a single field uniform dose pencil beam scanning proton plan was optimized on the planning CT (planCT) and on the scCBCT. Both plans were irradiated on patient-specific 3D printed head phantoms with inserts for film (all patients) and gel dosimetry (one patient). Gel readout was performed with magnetic resonance imaging. Proton range differences (PRDs) (80 % distal fall-off) were calculated from the dose distributions. The PRDs from the measurement were compared to PRDs originating from a dose calculation of both plans on the planCT (simulation) and to PRDs from the original dose on planCT and its recalculation on scCBCT (recalculation). The recalculation approach did not incorporate optimization differences, therefore simulation and measurement PRDs were corrected for comparability.

Results
High agreement was observed between the PRDs of the simulation and the measurements with film and gel (see evaluation of the PRDs in the film plane in Figure 1). The median values and IQR of the PRD maps comparing the gel measurement, simulation and recalculation approach showed a deviation of less than 0.7 mm and 0.5 mm, respectively.

Summary
A new measurement-based evaluation of in-room image data for adaptive proton radiotherapy was established and evaluated.

Acknowledgements:
FöFoLe #994
Appendix 1

Figure 1: PRD profiles in the film plane for the three patients.
Introducing a semi-automated framework for variable relative biological effectiveness (RBE) recalculations of clinical proton treatment plans

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8University Hospital Essen, Essen, Germany

Introduction
Recent studies show a linear energy transfer (LET) driven variable relative biological effectiveness (RBE) in proton therapy (PT), which challenges the current clinical use of a constant RBE. However, clinical treatment planning systems (TPS) do not provide variable RBE calculations yet. Here, a framework to inform clinicians on treatment plan safety in view of a variable RBE in clinical routine is presented.

Materials & Methods
An IronPython script for the TPS RayStation was developed providing a graphical user interface to recalculate LET and variable RBE-weighted dose ($D_{\text{RBE}}$) for clinical treatment plans (Fig.1). Automatization included transfer of clinical treatment plans to the research version of RayStation, calculation of proton dose-averaged LET and $D_{\text{RBE}}$ using a predefined variable RBE model (Wedenberg et al.) with adjustable tissue-specific radiosensitivities and saving LET and $D_{\text{RBE}}$ as evaluation doses.

Recalculations with the clinical hardware (Intel Xeon E5-2680, 40x2.8GHz, 128GB RAM) were made for two pediatric brain tumour patients with partial brainstem involvement in the planning target volume (PTV,Fig.2). Treatment plans were evaluated in terms of near-minimum, median and near-maximum dose to the PTV and brainstem.

Results
Clinical plan export and recalculation took less than 30 minutes for each patient. Considering $D_{\text{RBE}}$ instead of $D_{1.1}$ altered dosimetric indices in the PTV by less than 1 Gy(RBE), except for the near-maximum dose differing up to 5.4 Gy(RBE). For the brainstem of patients 1 and 2, predicted near-maximum $D_{\text{RBE}}$ increased by 8.1 Gy(RBE) and 4.8 Gy(RBE), respectively. A conservative brainstem tolerance dose of 54.0 Gy(RBE) adopted in the past was only exceeded for patient 2, where the predicted near-maximum $D_{\text{RBE}}$ of 58.0 Gy(RBE) still complied with modern clinical protocols.

Summary
Recalculation of patient-specific LET and $D_{\text{RBE}}$ distributions is feasible in clinical routine. It helps identifying potential risk regions in individual patients and correlations between LET distributions and treatment-related toxicity in large retrospective patient cohorts in PT.
Fig. 1: Visualization of the framework for fast recalculation of clinical treatment plans. The clinical treatment plan assuming a constant relative biological effectiveness (RBE) of 1.1 ($D_{1.1}$) is exported from the clinical RayStation (v9B, red box) to its research version (v8.99.30, blue box). The script automatically calls the Research RayStation implemented Monte Carlo scoring extensions to calculate the proton dose-averaged linear energy transfer ($\text{LET}_d$) and variable RBE-weighted dose ($D_{\text{RBE}}$). Advanced settings allow for selection of LET definition and variable RBE models. $\text{LET}_d$ and $D_{\text{RBE}}$ can be evaluated as additional information to $D_{1.1}$ in RayStation.

Fig. 2: a) Clinical dose distribution for Patient 1 considering a constant relative biological effectiveness (RBE) of 1.1 ($D_{1.1}$) and b) the recalcuated variable RBE-weighted dose ($D_{\text{RBE}}$) are shown together with c) the dose-volume-histogram (DVH) for $D_{1.1}$ (solid) and $D_{\text{RBE}}$ (dashed) for the planning target volume (PTV, turquoise) and the brainstem (black). $D_{1.1}$, $D_{\text{RBE}}$ and the DVH for Patient 2 are shown in d), e), and f), respectively. Three beams were used for each patient to deliver a median dose of 54 Gy (RBE) to the PTV in 30 fractions. The in-vitro data-based model from Wedenberg and others (DOI: 10.3109/0284186X.2012.705892) was used for variable RBE calculations with $\alpha/\beta$ of 10 Gy in the PTV and 2 Gy otherwise.
The influence of beam and organ motion on pancreas proton irradiations

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Introduction
The necessity for motion compensation in particle therapy depends on the anatomy, motion amplitude and underlying beam delivery technology. Existing treatment concepts for pancreatic cancer patients classified as small movers can be still improved. In this retrospective study the potential benefit of rescanning and the need for motion mitigation was investigated for proton treatment of pancreatic cancer.

Materials & Methods
The dose distributions of 13 pancreas patients treated with hypo-fractionated proton therapy (pulsed scanned pencil beams delivered by a synchrotron) were analysed based on accelerator logfiles, 4DCT data and breathing patterns extracted from the surface camera (C-Rad). Dose prescription was 25 and 37.5 Gy(RBE) to the PTV1 (ITV of GTV + 5mm) and PTV2 (high risk GTV + 5mm) (5 fractions SIB). If necessary, the dose was split into two fractions simulating volumetric rescanning. The TPS RayStation8B (MCv4.2) (RaySearch) was used for clinical treatment planning employing robust optimisation for mitigating different organ fillings. Phase-based 4DCT data was acquired at the time of planning and sometimes also during treatment. The delivery time structure was extracted from accelerator logfiles. In combination with the breathing-time structure, the time-resolved dose distribution was calculated on the 4DCT phases. This dose distribution was mapped onto the planning CT using deformable image registration and the dose distribution from each fraction was summed to obtain the total accumulated dose.

Results
The analysis of the first three patients confirmed the robustness of the treatment plans with respect to the interplay of beam and organ motion. The maximum amplitudes observed were 1.3, 1.9 and 3 mm. Rescanning for the 3mm amplitude did not show any relevant effect on the interplay. The retrospective 4D dose tracking revealed that D50 % of the CTV never varied by more than 1.6 %, even with a beam-on time variation of up to 10 %. Changes in the dose statistics of up to 20 % were observed for OARs.

Summary
The hypo-fractionated proton treatment for pancreatic cancer patients with robust optimisation and the selection of optimal beam entrance directions showed to be robust against intra-fractional movements. Within this study necessary tools to investigate the behaviour of carbon ions for pancreas treatment with a synchrotron were developed.
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²Prostate Cancer Center Hamburg-Eppendorf, Martini Klinik, Hamburg, Germany
³Hamburg University of Technology, Institute of Product Development and Mechanical Engineering Design, Hamburg, Germany

Introduction
Delivered dose in external-beam radiotherapy (RT) is mostly limited by tolerance of organs at risk (OARs). In the case of prostate cancer (PCa), the whole prostate is typically irradiated, even though tumor localization obtained during biopsy is known. In some cases, however, individualising dose escalation by including biopsy information offers the opportunity to implement focal RT, i.e. to increase delivered dose and thus tumor control probability (TCP) without increasing the dose to OARs.

Materials & Methods
A group of 11 PCa patients was investigated in this work. A model-based image registration was developed to segment the prostate into anatomical zones, so that the localization of the biopsy information could be integrated for lesion contouring. Individual intensity-modulated radiotherapy plans were created for focal radiotherapy. The whole prostate received a total dose of 75.6 Gy, while a simultaneous integrated boost (SIB) to the histologically-confirmed lesion was planned using biological optimization.

Results
The mean values of some treatment plan dose-volume parameters are summarized in Table 1. The SIB dose for patients with large or multiple tumor sites reached maxima of about 90 Gy. Small, single tumors far from OARs could be escalated up to 124 Gy with a mean dose of 102 Gy. With respect to the original plans, estimated TCP increased from 34 - 94 % (depending on the used model) to about 99 %. At the same time, the dose-volume parameters for bladder and rectum did increase only slightly.

Summary
Tumor localisation data obtained during biopsy can be used in focal RT to create individual treatment plans with boosted dose of more than 100 Gy while adhering to OAR constraints. The workflow will be further investigated using biopsy and irradiation phantoms.

Appendix 1

<table>
<thead>
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<th>Original plans</th>
<th>Focal RT plans</th>
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<tr>
<td><strong>Bladder</strong></td>
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<tr>
<td>$D_{15%}$[Gy]</td>
<td>55.2 ± 16.9</td>
<td>55.4 ± 15.3</td>
<td>42.3</td>
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<td>$D_{25%}$[Gy]</td>
<td>41.3 ± 18.1</td>
<td>44.4 ± 16.2</td>
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<td>35.2 ± 15.8</td>
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<td>$D_{50%}$[Gy]</td>
<td>21.8 ± 14.8</td>
<td>24.4 ± 14.2</td>
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<tr>
<td><strong>Rectum</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$D_{15%}$[Gy]</td>
<td>67.2 ± 4.9</td>
<td>70.4 ± 4.2</td>
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<tr>
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</tr>
<tr>
<td>$D_{35%}$[Gy]</td>
<td>46.3 ± 8.3</td>
<td>52.3 ± 6.9</td>
<td>43.6</td>
</tr>
<tr>
<td>$D_{50%}$[Gy]</td>
<td>35.2 ± 9.7</td>
<td>42.8 ± 6.8</td>
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<td><strong>Boosted Tumor</strong></td>
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<tr>
<td>$D_{15%}$[Gy]</td>
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<td>81.7 ± 3.9</td>
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<tr>
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<td>86.1 ± 4.5</td>
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<td>$D_{50%}$[Gy]</td>
<td>n/a</td>
<td>100.6 ± 10.1</td>
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Table 1: Mean values of dose-volume parameters for the whole patient cohort and a patient with small unilateral histologically confirmed tumor.
Effectiveness of pencil beam scanned proton beam tracking for lung tumor treatments

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\textsuperscript{2}ETH Zurich, Department of Physics, Zurich, Switzerland
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Introduction
Although interplay effects can severely distort the dose for pencil beam scanned (PBS) proton therapy, PBS is also ideally suited for tumor tracking. We performed a comprehensive simulation study for the effectiveness of PBS tracking for lung.

Materials & Methods
56 synthetic 4DCT(MR)Is, based on 7 lung cancer CTs each warped by 8 irregular motion patterns extracted from 5 multi-cycle volunteer 4DMRIs (superior-inferior isocenter displacements up to 15.4 mm) were generated. 2-field, single-field-uniform-dose plans were calculated for each CT. 4D dose calculations for no motion mitigation, ideal 2D (lateral tracking only) and 3D tracking (additional range adaption) with and without re-scanning were performed, considering different starting phases. Resulting 4D dose distributions were analyzed using CTV V\textsubscript{95\%}, D\textsubscript{5\%}-D\textsubscript{95\%} as well as mean healthy lung dose.

Results
Results for two 4DCT(MR)Is and for all CTs using the same motion pattern are shown in figures 1 and 2. Over all 4DCT(MR)Is, tracking effectiveness is patient specific. Compared to the static plan, V\textsubscript{95\%} decreases on average by 21.9\% for no tracking, 28.3\% for 2D and 25.0\% for 3D tracking. Combining tracking with 4-times volumetric re-scanning only leads to marginal improvements of V\textsubscript{95\%} (2D:+1.8\%, 3D:+1.3\%) compared to tracking alone. Generally, tracking only improves plan quality for 3 anatomies (small targets) but leads to worse coverage and homogeneity for the larger 4 tumours. However, tracking significantly reduces dose to surrounding healthy tissue.

Summary
Tracking can reduce the dose to healthy tissue but cannot recover target coverage in the presence of respiratory motion, even combined with re-scanning. A combination with additional motion mitigation techniques, such as gating or 4D optimization, is necessary to assure sufficient 4D plan quality.

Appendix

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Doses and DVH for two 4DCT(MR)Is.}
\end{figure}
Figure 2: Boxplot $V_{95\%}$ and $D_{5\%}$-$D_{95\%}$ CTV and mean lung dose for one motion pattern and PTV volumes.
Dosimetric benefits of daily treatment plan adaptation for prostate cancer stereotactic body radiotherapy based on synthetic cone-beam CT

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Introduction
Ultra-hypofractionation is increasingly applied for prostate cancer, demanding for higher accuracy of daily treatment deliveries than in conventional image-guided radiotherapy (IGRT). Together with recent developments of deep learning-based synthetic CT (sCT), adaptive radiotherapy (ART) techniques such as daily treatment plan modifications can address this issue and thus were evaluated with regard to dosimetric benefits over IGRT.

Materials & Methods
According to the PACE-C trial treatment regimen (5x8Gy), treatment plans for 32 patients were retrospectively created. sCT were generated based on five daily CBCT per patient using a previously trained cycle-generative adversarial network. Subsequently, three different treatment plan adaptation approaches were analysed on sCT and compared to the IGRT approach: Segment aperture morphing with segment weight optimization (ART1), with additional shape optimization (ART2) and a full re-optimization (ART3). Dose distributions were evaluated regarding dose-volume parameters and a penalty score.

Results
The ART1, ART2 and ART3 approaches substantially reduced the V37Gy(bladder) and V36Gy(rectum) obtained by the IGRT approach from a mean of 8.7 cm³ and 2.2 cm³ to (6.5 cm³, 6.4 cm³, 5.4 cm³) as well as to (1.6 cm³, 1.6 cm³, 1.3 cm³), respectively. The ART1 approach required an average calculation time of 0.9 min and yielded insignificantly different doses to organs at risk (OAR) compared to the ART2 approach. Being accumulated over the entire patient collective, a penalty score revealed that dose-volume parameters of IGRT were reduced by 76.2 %, 73.5 % and 91.1 % through the three adaptive re-planning methods.

Summary
Adaptive treatment planning approaches were proven to adequately restore relevant dose criteria of reference plans on a daily basis. Dosimetric benefits over conventional IGRT were either achieved through increasing target coverage (ART1+ART2 approaches) or sparing of OAR (ART3 approach). Combined with the application of anatomical metrics and a penalty score, the obtained results potentially facilitate the decision of when to apply which adaptation strategy.
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Introduction
Advanced dosimetric calculations and sophisticated phantoms have allowed for more personalized dosimetry. However, advanced dosimetry should be accompanied by information on the limitations and accuracy of the approach. In this study, we investigate the accuracy of a size-adjusted dose estimation for chest radiography.

Materials & Methods
A Monte Carlo framework was used to calculate the dose conversion factors (DCF) for size-adjusted effective and organ dose of 44 phantoms. Regression curves of the DCF as a function of the water equivalent diameter (WED) were obtained and the DCF for every WED in the range 15.0cm to 40.0cm (steps of 0.1cm) were calculated.

As in projection radiography there is no direct information about the patient size, a methodology was developed to estimate the patient’s WED by using information from the DICOM-header. Validation of the method in chest radiography showed maximal differences of 15% between the estimated WED and the real WED.

The 15% difference of WED was translated to dose differences by obtaining the DCF(WED+15%) and DCF(WED-15%) for every WED in the range (DCF(WED) versus DCF(WED±15%)).

The results were compared to the accuracy of the dose calculations with standard-size conversion factors (DCF(WED) versus DCF(WED=27.5cm)).

Results
The error of ±15% for the estimated WED resulted in maximal error of the size-adjusted effective dose of ±17%. For lung, the error ranged from -12% to 13%, while for breast it ranged from -41% to 65%. When using conversion factors meant for a standard-size patient, maximal errors were ±38% for effective, -23% to 29% for lung and -64% to 181% for breast dose (figure 1).

Summary
Although inaccuracies in size-adjusted dosimetric calculations exist, the new methodology showed improved accuracy compared to using standard-size conversion factors, especially for underweight and overweight patients.
Study on the radiation protection effect of a novel two-component head protection for fluoroscopy-guided interventions.

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²Klinikum Dortmund, Klinik für Radiologie und Neuroradiologie, Dortmund, Germany

Introduction
In fluoroscopy-guided interventions, the unprotected head is the most exposed area of the user besides the extremities. The protective effect of conventional lead shielding for the head is limited due to the scattered radiation generated in the lower head region. A novel two-part protective system consisting of a modified thyroid collar (lead equivalent 0.35 mm) and a head protection (lead equivalent 0.25 mm) is intended to solve this problem. In a two-month pilot study, this system was tested under real-life conditions using thermoluminescent detectors (TLD).

Materials & Methods
Thermoluminescent detectors (TLD) based on LiF:Mg,Ti (MTS-N powder) were used for the measurements. The TLD were calibrated to the equivalent dose to the eye lens $H_p(3)$ and corrected for the used radiation quality and background radiation. For simultaneous measurement of radiation exposure with and without protective clothing, a TLD was fixed to the inner and outer side of each measuring point (Fig. 1). Two sets, each consisting of a head protection and a thyroid collar, were prepared. Set 1 was used exclusively for neuroradiological interventions and Set 2 exclusively for general radiological interventions.

Results
To compare the staff exposure in general radiology and neuroradiology, the outer dose values were normalized to a dose area product (DAP) of 10,000 $\mu$Gy·m². The mean normalized outer dose was $(21.68 \pm 8.80) (\mu Sv/10,000 \mu Gy \cdot m^2)$ at the head protection and $(45.17 \pm 26.00) (\mu Sv/10,000 \mu Gy \cdot m^2)$ at the thyroid collar. The mean attenuation achieved by the head protection was $(82.9 \pm 9.4) \%$, compared to $(96.1 \pm 0.8) \%$ for the thyroid collar.

Summary
Fluoroscopy-guided interventions lead to a significant exposure of the head area for the examiner. The novel protection system tested here, consisting of a modified thyroid shield and a head shield, can considerably reduce the dose.

Appendix 1

![Figure 1: TLD measuring points]
V45 Improving the analysis of TL dosimeter with convolutional neural networks

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Introduction
In routine personal dosimetry the aim is to estimate the radiation dose for one month. Dosemeters using thermoluminescent materials can provide further information like the time of irradiation or the number of irradiation fractions within the monitoring interval. The Lehrstuhl Experimentelle Physik 4 at the TU Dortmund University, in cooperation with the Materialprüfungsamt NRW, is developing multivariate glow curve analysis techniques, which allow the extraction of information beyond the irradiation dose estimation. Usually this requires a complex deconvolution process of the thermoluminescence signal. In this study we try to simplify this process by using a deep learning approach.

Materials & Methods
First studies of the prediction of the irradiation date using the deconvolution process in combination with a feed forward neural network were performed for a single irradiation scenario [1]. However, this approach has its limitations due to the underlying glow curve model and the uncertainties arising from the complexity of the deconvolution process. We present a new approach using a CNN, where the raw glow curve signal is used as input parameter. More than 3000 measured glow curves are used for the training of the CNN.

Results
The result of our research is the estimation of the irradiation date for a single irradiation scenario with a prediction uncertainty of up to 4 days within a monitoring interval.

Summary
We present studies with CNNs by using the raw glow curve signal as input. In addition to the irradiation dose, more accurate information on the time of irradiation or the number of irradiation fractions can be obtained, which introduces additional values to the use of passive dosimeters.

Reference
[1] F. Mentzel et. al. „A machine learning approach to glow curve analysis“, Radiation protection dosimetry, 2019
Introduction
Development and usage of more efficient X-ray systems in clinical diagnostic radiology leads to less dose outside the used radiation fields. Is lead shielding of the abdomen still useful in thorax radiography?

Materials & Methods
EGS-Ray was used in Monte Carlo simulations of thoracic radiography with and without lead protection. The surface dose of the abdomen was determined. Measurements were done with an Alderson Rando phantom. Doses were recorded with OSL dosimeters. For high dose levels, following settings were adjusted: tube voltage: 125kV, tube current-time product: 1000mAs, source-detector distance: 180cm, field size: 30.9cmx32.8cm, which corresponds to a dose 500 times higher than a standard image. Ten OSL dosimeters were used in every measurement (figures 1, 2). One measurement was made without protection, one with a half apron in front, one with a half apron in the back and another with aprons full around.

Results
Simulations showed no significant dose reduction with lead shielding, figure 3. Results for one radiograph with 2mAs are shown in figure 4. The maximum dose saved by using lead shielding was 40 nGy.

Summary
The total dose without attenuation is very low and comparable to several minutes of natural radiation. As a result a lead rubber apron is not necessary, but if an implementation is wished, the patient should be wearing an detector-sided apron. In relation to the study of Roth et al. the results are slightly lower but in the same order.

References

Appendix

Figure 3 Positioning of OSL dosimeters

Figure 2 Measurement positions
Figure 4 Results of the Monte-Carlo-Simulation, left with lead apron, right without

Figure 5 Dose at measurement positions with different protection
V47  An approach to unify dose quantities in CT and CBCT applications

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Introduction
There is a steadily increasing use of cone beam computed tomography (CBCT) in clinical applications. Despite the growth of clinical use and the fact that an increasing number of imaging tasks can be performed with both systems, dose quantities within the worlds of CT and CBCT still remain clearly separated. In CT, the volume-based quantities CT dose index (CTDI) and dose length product (DLP) are generally used. In CBCT, the conceptually very different incident dose quantity dose area product (DAP) is in use. The different approaches hinder the direct comparison of patient exposure in CT and CBCT. In order to develop a unification framework for both dosimetry concepts, the Federal Office for Radiation Protection (BfS) set up a research project with project ID 3619S42462.

Materials & Methods
A theoretical basis for the unification of volume-based and incident-based dose quantities was developed. On an number of CBCT systems measurements of volume-based dose quantities (DLP, CTDI300, f(0)) were performed using a triple CTDI-phantom with 16 cm and 32 cm diameter. Correspondingly, the DAP was measured. All equipment used was calibrated and energy corrected. On CT systems DLP was measured accordingly. A corresponding DAP was determined from measurements of the air kerma rate profile along the structure of the bow tie filter and the in-air central axis air kerma-length product.

Results
Conversion factors k = DFP / DLP were determined as approx. 35 cm for the 16 cm CTDI- and 60 cm for the 32 cm CTDI-phantom. Exact values, however, depend on the incident spectrum. The dependence can be fitted with reasonable uncertainty.

Summary
A unification of dose quantities from CT and CBCT seems feasible. First conversion factors were determined that seem stable for different CBCT systems.
Homogenized procedure for the acquisition and physical-technical analysis of export data from various dose management systems

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Introduction

Based on the German radiation protection law, there is a need of Medical Physics Experts in Diagnostic and Interventional Radiology for the operation of x-ray systems. It is not necessary for the expert to attend all procedures. Therefore, he can act as an external consultant. In order to analyze and evaluate the dose data exported of various dose management systems (DMS) automatically, a specific tool was developed.

Materials & Methods

First, the user needs the DMS for the purpose of getting the dose documentation of the x-ray systems. QlikSense was used to enable the analysis of the export data of various DMS. In that software, tables with different functions giving various aspects of the analyses are generated automatically by predefined templates and commands within the analysis tool. The results can then be exported as a report.

Results

With this tool, the analysis can be accelerated and done automatically. Moreover, the results of export data are presented in a standardized manner, and it is also possible to compare various institutions. Information to compare various systems within an institution, providing process control as well as quality management of the work with x-ray systems is the result of this tool.

Summary

The tool enables an efficient workflow and is less prone to errors in the analysis of dose data by automated evaluation. In addition, it can be used to review and improve the current workflow because it provides a structured overview of the dose documentation. A comparison between various systems is also provided by standardized information presentation.

Appendix

Figure 6 General overview of the investigations and their diagnostical reference values compared with the applied dose values
Session 12 | Free Topics 2

V49  Comparison between Eclipse AAA and Acuros XB calculation algorithms using VMAT on bony target volumes and its impact to spinal cord dose

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Introduction
On the Eclipse TPS, the final dose of VMAT plans is calculated using the Analytical Anisotropic Algorithm (AAA). However, the calculation time may take several minutes, with increased plan complexity. The Acuros XB (AXB) algorithm uses mathematical methods with an accuracy comparable to Monte Carlo methods. Two approaches for the final dose can be chosen, dose-to-medium (Dm) and dose-to-water (Dw). The aim is to compare these 3 approaches in dosimetric terms on bony target volumes and its impact to the spinal cord dose.

Materials & Methods
12 patients with target volumes located on the thoracic or lumbar vertebrae were selected. 3 VMAT plans using one arc with photon energy of 6 MV were generated for each patient with Eclipse version 15.6: AAA, AXB-Dm and AXB-Dw. The $D_{98\%}$ and $D_{2\%}$ doses for PTV, maximum dose ($D_{\text{max}}$) to spinal cord and plan $D_{\text{max}}$ were evaluated.

Results
The results for 5 patients are presented on Table 1. The three approaches deliver at least the 95% of the prescribed dose to the PTV. $D_{2\%}$ doses were large for both AXB plans compared to AAA, with slight higher values on AXB-Dw. The same trend was observed for the plan maximum dose. The spinal cord dose was higher with the AXB-Dm approach, compared to the other two plans. The calculation time for both AXB plans was on average 30 seconds, compared to 3 minutes for AAA.

Summary
Both AXB algorithms were faster than the AAA approach. On a first glimpse, the AXB-Dw method shows higher doses where bony tissue is present. Conversely, the AXB-Dm approach shows higher maximum doses to the spinal cord. The data for the whole patient cohort will be presented at the conference.

Appendix

Table 1. Median (range) of dosimetric values in percentage for 5 patients

<table>
<thead>
<tr>
<th></th>
<th>AAA</th>
<th>AXB-Dm</th>
<th>AXB-Dw</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D_{98%}$</td>
<td>95.9</td>
<td>96.2</td>
<td>95.8</td>
</tr>
<tr>
<td>$D_{2%}$</td>
<td>101.9</td>
<td>102.6</td>
<td>103.3</td>
</tr>
<tr>
<td>Spinal cord</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D_{\text{max}}$</td>
<td>102.8</td>
<td>104.1</td>
<td>102.9</td>
</tr>
<tr>
<td>Plan</td>
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<tr>
<td>$D_{\text{max}}$</td>
<td>104.3</td>
<td>107.1</td>
<td>108</td>
</tr>
</tbody>
</table>
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Introduction
A TrueBeam® (Varian Medical Systems, Palo Alto, CA, USA) at our site is equipped with two surface tracking systems: The ExacTrac Dynamic® V1.0 (ETD; Brainlab AG, Feldkirchen, Germany) and the AlignRT® V5.1.2 (ART; VisionRT Ltd, London, UK). To investigate which of these systems can detect intrafractional motion of the patient during treatment delivery more accurately is part of the preclinical validation of the HyperArc® (HA; Varian Medical Systems) workflow. The accuracy at extreme couch angles (90° and 270°) is of particular concern for this ETD system since the ETD 3D camera used for surface monitoring is installed about 15° off the gantry rotation axis.

Materials & Methods
A pelvic phantom (Brainlab AG) was positioned on the Varian PerfectPitch 6-DoF Couch at various couch angles (0°, 45°, 90°, 270° and 315°) using ETD X-ray imaging and baselines were recorded for both surface monitoring systems.
ETD and ART tracked the phantom surface simultaneously in six degrees of freedom while a couch translation of 1.5mm or a couch rotation of 1.5° was performed. The measurements were compared to the results of an ETD X-ray verification.

Results
While ART provided stable data unaffected by external conditions, ETD data initially showed strong fluctuations due to the colour and reflectivity of the phantom surface. This effect was minimised by covering the phantom with fabric. ETD and ART detected phantom movements to an accuracy of ±0.3mm and ±0.2° at all investigated couch angles. The offset of the ETD 3D camera from the gantry rotation axis does not considerably affect the precision of the ETD measurements.

Summary
Both ETD and ART are capable of detecting intrafractional motion of the patient adequately to an accuracy of ±0.3mm and ±0.2°. These inherent uncertainties in both surface monitoring systems need to be considered pre-treatment to ensure optimal therapeutic outcomes.
A CT histogram analysis as a predictor for the modulation effect in heterogeneous materials like lung


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Introduction
In heterogeneous or porous materials, the Bragg peak is degraded. In particle therapy, this becomes relevant for irradiations where the particle beam passes the lung, as the microstructure of the alveoli leads to this degradation and this again can lead to an underdose in the treatment volume. Previous works quantified the effect on the dose distribution. However, the main free parameter which dramatically influences the effect, is the so-called modulation power. The aim was to develop a model that estimates this modulation power with the available CT information to minimize the uncertainties for the dose estimations.

Method
Different modulating materials were scanned in a conventional clinical CT and in-beam measurements were performed to obtain a valid value for the modulation power. The beam region was then contoured in the CT-scans and histograms were produced and analyzed. A model was established that relates the measured modulation power to the mean and the width of the CT-histogram.

In a second step, the model was validated with CT and in-beam measurements of frozen porcine lung samples.

Results
For modulation powers in the clinical range (0.1mm-0.45mm), the obtained values are in good agreement with the measured modulation powers (figure 1). For porcine lung samples, the values show higher uncertainties, which are, in a clinical context, neglectable.

Conclusion
The model allows an estimation of the modulation power and the effect on the dose distribution with a setup available at every clinic. Even though, the model has higher uncertainties and limitations, in-beam measurements, which are a direct measurement of the effect are always inherent with additional dose given to the patient, which can be spared by the use of the presented model.
Fig. 1: Modulation power calculated via the CT-histogram analysis plotted against the measured modulation power for heterogeneous substitutes (green) and the porcine lung sample (blue).
Introduction
For absolute and relative QA-measurements of ruthenium-106 ophthalmic applicators a special water phantom is under development (BetaCheck-106, Eckert&Ziegler-Bebig). The phantom will come with a calibrated detector, which allows absolute depth dose measurements. In this work several detectors were evaluated and compared to the reference.

Materials & Methods
The BetaCheck-106 is a small water phantom for the measurement of depth dose curves between 2mm and 10mm. The depth can be adjusted with a micrometre screw and depth is calibrated using a steel ball. The provided reference detector (Diode E, Type 60017, PTW-Freiburg) is calibrated and allows absolute dose-rate measurements. Different other detectors (Diode E 60017, PinPoint 31014, MicroDiamond 60019, PTW-Freiburg) were compared to the reference detector and the certificate. The detectors were cross-calibrated (linear fit) against the reference and PDDs (2mm-10mm) of four CCB-type applicators with different activities (1-100mGy/min in 2mm depth) were collected. Due to its geometry, the first measurement point of the PinPoint is in 4mm. All PDDs were measured multiple times on different days, to verify the reproducibility.

Results
For the applicator with the highest activity the difference between the Diode E detectors and the certificate is less than 7 % for all depth and doserates (figure1). The microDiamond shows deviations >10 % for the highest depth and doserates <8mGy/min. The PinPoint shows deviations within 10 % for depth smaller than 7mm (18mGy/min). Similar results between doserate and deviation were observed for the other applicators. Reproducibility for all detectors was better than 2 %.

Summary
All detectors are suitable for PDD measurements and show deviations smaller 10 % for doserates >30mGy/min. At higher depth (e.g. lower dose rates) the Diode E is superior and shows smaller errors.

Figure 1: Depth dose measurements and deviation from certificate (right axis)
Introduction
Microbeam radiotherapy (MRT) and FLASH are innovative radiotherapy concepts with a lower normal-tissue toxicity than conventional radiotherapy. However, there is yet no suitable x-ray source for clinical application. One promising source is the line-focus x-ray tube (LFxT). Its design enables very high dose rates through a high heat resistance at the focal spot by shifting the main heat absorption mechanism from heat conduction to heat capacity. Heat management is a main technical challenge of the preclinical LFxT prototype (300 keV, 90 kW electron beam, 200 m/s target velocity), which we are currently constructing.

Methods
We simulated the maximum temperature increase at the focal spot with Monte Carlo (TOPAS) and finite element methods (FEM) for different spot widths (length 30 mm). The expected temperature increase was numerically calculated for both the heat conduction and the heat capacity limit. Further, we investigated the temperature course of the rotating target and the vacuum chamber during 20 s irradiation time followed by 20 min cooling using FEM.

Results
The electron beam deposited 54.6 kW into the target. With focal spot widths \( \ll 1 \) mm, the LFxT ran in the heat capacity limit, where the maximum temperature increase was much lower than according to the heat conduction limit, see figure 1. The temperature course of the target reached a steady state after four irradiation cycles only if active cooling was applied at the target shaft. Due to backscattered electrons, the vacuum chamber heated up highest (691 °C without, 250 °C with active cooling) opposite to the focal spot at the transition to the electron beamline and at the x-ray window, see figure 2.

Summary
We validated the heat capacity limit for the LFxT with simulations. Active cooling of the target and the vacuum chamber enables stable operation of the preclinical LFxT prototype.
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Appendix

Figure 1: Maximum temperature increase at the focal spot according to the heat conduction limit and the heat capacity limit.

Figure 2: Temperature distribution at the inner surface of the vacuum chamber after 20 s irradiation time with active cooling.
Heat transfer simulation in a prototype graphite probe calorimeter using finite elements method

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Introduction
With rising interest in clinical usage of FLASH radiotherapy, opportunities for graphite probe calorimeters present itself. However, the calibration of these calorimeters remain an elaborate task. To potentially alleviate this problem, this work aims to simulate a self-calibration process of built-in thermistors.

Materials & Methods
By adopting geometry and materials from previously built calorimeters [1] in Matlab and inserting thermistors (one as heater, one for measurement) into the graphite core, the heat transfer in the calorimeter is calculated by using the finite elements method. The calorimeter is simulated as if in a water bath, by setting appropriate boundary conditions. The temperature in each region is calculated by averaging over all nodes within the region. For calibration a defined amount of energy is deposited in the graphite core by the first thermistor and measured by the second. In practice, the amount of energy deposited via Joule heating can be determined by electrical measurements, provided appropriate corrections are applied. To evaluate necessary corrections, a finite element model of the graphite probe calorimeter was implemented in Matlab.

Results
A heat transfer model of the graphite probe calorimeter was successfully implemented in Matlab, enabling the determination of energy loss into the insulation and periphery structures of the calorimeter, as well as the equilibrium time for reliable measurements.

Summary
The feasibility of heat transfer simulations within a prototype graphite probe calorimeter was shown using finite elements analysis in Matlab.

References
Session 13 I Ultra-High Dose Rate Radiotherapy – FLASH

F9 Radiation-chemistry for FLASH treatments with ion beams

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Introduction
In a typical ion beam treatment, the LET distribution changes over the irradiated volume spanning a range of several tens of keV/µm. Additionally, the use of scanning systems to cover extended irradiation volumes causes a very inhomogeneous dose-rate distribution within the treatment duration. Eventual LET and dose/dose-rate dependencies have to be considered when investigating possible FLASH effects.

Materials & Methods
The TRAX-CHEM Monte Carlo code [1] was used to investigate several radiation chemical mechanisms considered to be relevant for the FLASH effect and for searching a possible differential effect between tumor and healthy tissues under different irradiation conditions. The impact of target oxygenation, different radical production and radical recombination processes have been studied by comparing proton and carbon treatment planning scenarios. The impact of inhomogeneous dose rate distribution when applying scanning techniques on radical recombination is analysed as well.

Results
Simulation and experimental results show that ions deplete an even smaller amount of oxygen compared to low LET radiation, predicting a negligible role of radiation-induced hypoxia for therapy compatible doses. Compared to proton radiation, carbon ions produce a much larger amount of radicals, however, track density effects lead to a larger contribution of the intra-track radical recombination. Recombination among radicals generated by different tracks is not predicted within the timeframe of a chemical stage, as chemical track overlap is not expected to occur even at typical dose-averaged dose rates up to >104 Gy/s.

Summary
All the investigated mechanisms predict a reduced FLASH effect with carbon ion irradiation conditions. If experimentally demonstrated, the persistence of FLASH effect with 12-C beams could contribute to rule out some candidate pathways considered also for explaining the effect at low LET radiation.

References
F10  *In vitro* FLASH experiments

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Introduction
Recent investigations have demonstrated that a high dose rate of radiation (above 40 Gy s⁻¹), also called FLASH irradiation, efficiently inhibits tumor growth, as the irradiation currently used with conventional dose rates (typically some cGy s⁻¹), while sparing the surrounding healthy tissues. FLASH has the potential to revolutionize cancer treatments. The molecular mechanism behind it is not yet clearly understood, but a prominent role for oxygen concentration and reactive oxygen species formation is the current hypothesis. The FLASH effect has been demonstrated both in vivo and in vitro. However, if there is a FLASH effect also using heavy ions, it has never been proved.

Materials & Methods
CHO-K1 cell response to irradiation at different dose-rates and at different levels of oxygenation was studied using clonogenic assay and DNA damage response (γH2AX) analysis.

Results
Clonogenic assay demonstrates a significant FLASH sparing effect, which is strongly oxygenation-dependent and mostly pronounced at 0.5% O2 but absent at 0% and 21% O2. The γH2AX results show a reduction in the residual foci signal at 1% O2, confirming the FLASH sparing effect observed with the clonogenic assay.

Summary
Our group performed for the first time FLASH irradiation using a carbon ion beam. We investigate, at different oxygen concentrations, the *in vitro* biological response of CHO-K1 cells compared to conventional dose-rate.
F11 3D range-modulators: dose simulations under the aspect of potential FLASH irradiation with protons.

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Introduction
Radiotherapy with dose rates above 40 Gy/s ("FLASH") could reduce side effects in healthy tissue and increase the therapeutic window. Cyclotrons, however, must be operated at the highest energy to provide the necessary dose rate. A 3D range-modulator (RM), optimized for single energy and individual tumour shape, may present an optimal solution for FLASH.

The range of the highest energy (about 38 cm at 250 MeV) must be adjusted to the tumour depth using a suitable absorber. This work uses Monte Carlo (MC) simulations to investigate the effect of absorber in combination with 250 MeV protons on the dose distribution behind a 3D-RM compared to a reference simulation with 151 MeV without absorber.

Materials & Methods
The dose distribution of a 3D-RM, previously optimized for 151 MeV protons and a complex tumour shape, was simulated in a water phantom (MC FLUKA). Two modifications were then performed: the energy was increased to 250 MeV and an approximately 19 cm thick PMMA absorber was positioned immediately behind the RM and in front of the water phantom.

In the subsequent simulation the dose from each scan-spot was scored individually, then assigned a weighting factor and optimized for a homogeneous dose in the target volume to account for the change in energy and scattering. The final simulation was performed with the optimized scan-spots.

Results
There is good agreement between both dose distributions, 151 MeV without absorber and 250 MeV with absorber. The dose in the target volume shows a high degree of homogeneity and conformity.

Summary
The 3D-RM is a promising method to achieve very fast treatment with a high degree of dose conformity and homogeneity in proton therapy with one energy. A 3D-RM in combination with a high proton energy and the appropriate absorber could enable FLASH irradiation in the future.
Joint Conference of the ÖGMP, DGMP and SGSMP

F12 FLASH-Dosimetry for carbon beam therapy

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2University of Applied Sciences THM, IMPS, Gießen, Germany
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Introduction
Ultra-high intensities of FLASH-RT lead to new challenges with regard to dosimetry. FLASH experiments at HIT (Heidelberg Ion Beam Therapy Center) have shown a significant loss of signal in the beam monitoring system and in the dosimetry ion chambers due to recombination effects.

Materials & Methods

Experiments: To enable accurate beam monitoring, this work investigates the recombination loss of different fill-gases in the parallel plate ionisation chambers (ICs) of the beam monitoring system when operated at FLASH conditions. Therefore, saturation curves (variation of the chamber voltage over a wide range 50 -2000 V) were measured for 80 %/20 % Ar/CO2 and pure He and also for He/CO2 mixtures as alternative fill-gases. Additionally, we performed dose measurements for FLASH irradiations with small thimble ('PinPoint') Ionisation chambers and acquired the corresponding saturation curves in a range of 50-800 V.

Modelling: In order to achieve more accurate predictions on the recombination effect, a numerical model for volume recombination in parallel plate ionisation chambers was developed. This includes a novel simulation of the space charge effect of the free charges in the detector volume and predicts that the space charge effect has a significant effect on the electric field.

Results:
Examples for saturation curves can be seen in the figure. Our measurements also show that the 96/4 He/CO2 mixture would show recombination losses of 2.7 % in the currently used ICs with 10 mm gap when operated at FLASH irradiation conditions which are feasible at GSI (typ. 5e9 ions in 150 µs). Reducing the gap size to 5 mm decreases the volume recombination loss far below 1 %. The model can well predict the shape of the saturation curves.

Summary
Dosimetry for Carbon FLASH is feasible (tested for < 5e10 ions/s). Saturation effects of beam monitors can be solved with a Helium/CO2 gas filling.
Dosimetry for FLASH radiotherapy with electron beams

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Introduction
Dosimetry for FLASH radiotherapy with electrons is a metrological challenge due to the ultra-high dose rates (UHDR) and pulsed structure of the beams with dose per pulse (DPP) of 0.6 – 10 Gy/pulse. Available ionization chambers (IC) show large deviations due to ion recombination which increases with increasing DPP. Current theories of ion recombination effects fail at UHDR. Hence, dosimetry is currently based on passive detectors (alanine, radiochromic films), which allow dose reading only after delay (hours, days). However, to characterize UHDR beams and the biological "FLASH-effect", reliable real-time measurements are needed. Promising approaches are detectors based on synthetic single crystal diamond and plane-parallel ICs with small electrode distance (gap).

Materials & Methods
A variety of microDiamond detectors, commercially available and prototypes, were investigated at ultra-high DPP. To determine the DPP reference, the beam current monitor was calibrated against alanine. Furthermore, the response of plane-parallel IC prototypes with small gap were tested.

Results
All microDiamonds respond linearly at low DPP (Fig.1). The response deviates from linearity with increasing DPP. The DPP value at which non-linear behaviour becomes significant varies between 0.1 and 2 Gy/pulse for commercially available microDiamonds depending on specimen (SN). However, prototypes (B1) demonstrated that the linear range can be extended.

![Figure 7: Dosimeters reading as function of actual DPP.](image)

The response of an ultra-thin-gap plane-parallel IC prototype is, even without application of any ion recombination correction, almost linear up to ultra-high DPP.
Summary
Prototypes of different active dosimeters show promising results for real-time dosimetry in UHDR electron beams.

Acknowledgement
This project 18HLT04 UHDpulse has received funding from the EMPIR programme co-financed by the Participating States and from the European Union’s Horizon 2020 research and innovation programme. Diamond prototypes are produced at the Industrial Engineering Department of Rome Tor Vergata University in cooperation with PTW.
Session 14 I Guidelines and Regulations in Brachytherapy

F14  State of the art and clinical evidence in GYN brachytherapy

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Introduction
The use sectional imaging and optimized treatment planning became state of the art for gynaecological brachytherapy. Several guidelines and clinical experience were published during the last years.

Materials & Methods
The current state of the art is described by a literature review.

Results
The most comprehensive guideline of the current state of the art is the ICRU report 89 [1]. It describes a concept for target definition, OAR dose assessment, and for prescribing, recording and reporting dose. Definition of the initial GTV, residual GTV as well as a risk based clinical target volume concept using MRI are a key message of this report. Clinical evidence for excellent local control has been published from the multicentre EMBRACE trial for the MRI only concept [2]. This study also provide dose response curves for disease outcome and different morbidity endpoints. The current evidence allows to define dose constraints for different dose and volume parameters linked to different anatomical and functional structures. Nowadays it became possible to perform a patient specific, risk adapted dose prescription protocol. An international consortium including GEC-ESTRO, IBS and ABS. currently writes guideline summarizing the existing knowledge for optimized treatment planning.

In daily clinical practice the MRI only approach for each individual fraction should be standard. However, several alternatives are available including offline approach with pre-treatment MRI and combination with CT and/or transrectal ultrasound. Specific care should be taken when using image registration and dose accumulation [3].

Summary
MRI based image guided adaptive brachytherapy leads to clinical change of practice in Europe, North America and Asia. The MRI only based adaptive treatment approach should be used as benchmark.

References
Introduction
Brachytherapy (BT) is a very successful treatment option for localised prostate cancer. The two main BT methods for this are using low-dose-rate (LDR) sources as permanent implant or temporary high-dose-rate afterloading techniques. In addition pulsed-dose-rate is applied in some centers. The methods used clinically are not standardized. So, it is complex to find consensual guidance in the application of prostate BT. In this overview we want to summarize mainly physical aspects of important international recommendations for prostate BT including imaging, treatment planning, and dosimetry.

Materials & Methods
To information presented here are collected from recent guidelines published by large international societies. Guidelines from GEC-ESTRO/ACROP [1-3], AAPM [4, 5], and ABS [6, 7] are considered.

Results
Prescription doses for I-125 are commonly 145 Gy, whereas for HDR there is range of dose prescriptions and also a variety of different fractions. Both methods can be used as boost or monotherapy technique. Margin concepts are explained as well as the needed imaging modality. Clinically used calculation algorithms are typically following the TG-43 formalism. Dosimetric impact, in particular of calcifications and inter-source absorption in LDR implants that can’t be considered using TG-43 formalism are published, but not yet covered in recommendations.

Treatment planning aspects and clinical goals will also be presented as needed dose indices for plan reporting. For LDR technique post-planning imaging and evaluation methods requirements are shown. LDR and HDR treatment technique base in most cases on real-time ultrasound imaging. As ultrasound is a crucial image modality for prostate BT recent quality assurance procedures are presented.

Summary
In this presentation an overview on existing guidelines for LDR and HDR prostate BT are presented. We put the focus on physical aspects and hope this will be of benefit for users to extract the needed information to improve clinical application in prostate BT.

References
Session 15 | Reporting of Incidents – Current Status

F16 Reporting of incidents - current status

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Introduction

Reporting of incidents has been made mandatory for all practitioners. Experience from the German Federal Office for Radiation Protection (BfS), a responsible authority in Germany and a clinical medical physicist will be presented and then discussed with one another.

Materials & Methods

The European Basic Safety Standards directive requires avoidance of unintended and accidental exposures [1]. If these occur nevertheless, they have to be analysed and reported. Annexes 14 & 15 of the German Radiation Protection Ordinance list examples of incidents that have to be reported to the authorities in Germany in particular [2]. The undertaking/practitioner must report incidents to the competent authority. The authority forwards information on incidents anonymously to the central office of BfS (BeVoMed database).

Results

In 2019, BfS recorded the following number of completed incident reports, broken down by medical specialty: x-ray diagnostics 7, interventions (diagnostics and therapy) 1, radiotherapy 49, nuclear medicine (diagnostics and therapy) 11 [3].

Summary

The number of incidents reported in the medical fields of X-ray diagnostics, interventions and nuclear medicine is conspicuously low compared to the number of examinations and treatments carried out. Clarification and an establishment of processes in the clinics and upon practitioners is still required. There are also some events which it is doubtful whether they are notifiable.

References

Introduction

There is increasing interest in using helium ions for radiotherapy, complementary to protons and carbon ions. A large number of patients were treated with $^4$He ions in the US heavy ion therapy project in Berkeley and novel $^4$He ion treatment programs are under preparation, for instance in Germany and Japan. $^3$He ions have been proposed as an alternative to $^4$He ions because the acceleration of $^3$He is technically less difficult than $^4$He. In particular, beam contaminations have been pointed out as a potential safety issue for $^4$He ion beams.

Materials & Methods

This motivated a series of experiments with $^3$He ion beams at GSI, Darmstadt. Measured $^3$He Bragg curves and fragmentation data in water are presented in this work [1]. The physical characteristics of $^3$He ion beams are compared to those of $^4$He, for which a large set of data became available from the preparation work at the Heidelberg Ion-Beam Therapy Center [2].

Results

The experimental comparison is supported by Monte Carlo simulations using the FLUKA code. The dose distributions (spread out Bragg peaks, lateral profiles) that can be achieved with $^3$He ions are found to be competitive to $^4$He dose distributions. The peak-to-entrance ratio is found to be significantly better for $^3$He ions. The effect of beam contaminations on $^4$He depth dose distribution is also addressed.

Summary

It is concluded that $^3$He ions can be a viable alternative to $^4$He, especially for future compact therapy accelerator designs and upgrades of existing ion therapy facilities.

Appendix 1

comparison of measured Bragg curves for $^3$He and $^4$He ions

Figure 1: Comparison of measured $^3$He and $^4$He Bragg curves
Appendix 2

Figure 2: Comparison of simulated $^3$He and $^4$He SOBPs (FLUKA simulation)

References


Monte Carlo calculation of beam quality correction factors in proton beams using FLUKA

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2Universitätsklinikum Giessen-Marburg, Klinik für Strahlentherapie und Radioonkologie, Marburg, Germany
3Marburg Ion-Beam Therapy Center (MIT), Marburg, Germany
4Marburg Ion-Beam Therapy Center (MIT), Marburg, Germany

Introduction
In the upcoming version of the IAEA TRS-398 Code of Practice, Monte Carlo calculated beam quality correction factors $k_Q$ for air-filled ionization chambers in clinical proton beams will be presented. So far, the Monte Carlo codes PENH and Geant4 have been used to calculate $k_Q$ factors. In this study, FLUKA was used to calculate $k_Q$ factors in order to extend the data situation.

Materials & Methods
The Monte Carlo code FLUKA was used to calculate the dose absorbed in a water-filled reference volume and the air-filled cavities of six plane-parallel and four cylindrical ionization chambers. The chambers were positioned at the entrance region of monoenergetic proton beams with energies between 60 MeV and 250 MeV. From these dose values, $k_Q$ factors were calculated.

Results
In figure 1 the $k_Q$ factors calculated in this study are shown along with values from the literature. In general, a good agreement between the codes can be seen for low and medium energies. For high energies, differences are pronounced while FLUKA and Geant4 lead to comparable results and $k_Q$ factors calculated with PENH tend to be larger.

Summary
FLUKA can be used for the calculation of $k_Q$ factors in clinical proton beams. The divergence of the Monte Carlo codes for high energies might be due to differences in the nuclear interaction models implemented in the codes. Nuclear interactions play a minor role for low and medium energies, leading to comparable results between the codes in this energy regime. For high energies, the nuclear interactions become more and more important and differences between the codes are correspondingly more pronounced.

Appendix 1

![Figure 1: Monte Carlo calculated $k_Q$ factors and comparison with values from the literature.](image-url)
Towards primary and secondary standards for dosimetry in Flash radiotherapy

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Introduction
The UHDPulse project is an EMPIR funded collaboration to develop dosimetry methods for FLASH modality and guidance for code of practice (CoP). In ultra-high dose (UDH) rate beams, the use of ionometry for absorbed dose measurement is not suitable due to high level of ion recombination. In this presentation, preliminary results of the investigation of ion chamber, calorimeter and alanine in UHD per pulse beams will be shown.

Materials & Methods
The response of different types of detectors has been measured in a 20 MeV UHD per pulse electron beam provided by the research accelerator at PTB Braunschweig. The measurement has been performed between 0.5 to 6 Gy-per-pulse. To monitor the beam, a non-destructive Integrating Current Transformer (ICT) is integrated in the beamline. The detectors used are plane-parallel chambers, alanine pellets and a probe-type graphite calorimeter. The ion collection efficiency of ion chambers has been obtained for a range of 0.4 to 2 Gy-per-pulse.

Results
The dependence of the ion collection efficiency is not systematically linear with the dose per pulse and intra-model variation is in the 2-5 % range as illustrated in figure 1. In figure 2, the depth dose measurement with calorimeter and ion chamber compared to Monte Carlo calculation is shown. The \( R_{50} \) measurement and simulation agree within 1 mm.

Summary
Although the project is still in early stage, calorimetry is showing promising results for NMI and clinical use. Calorimetry gets simpler at UHD beam as the dose delivery is in a few seconds or less. The lack of precise accurate measurements and accurate theoretical model of the ion recombination hampers the use of ionometry in UHD beam.

Appendix 1

Figure 1: Ion collection efficiency in UHD per pulse beams

Figure 2: Depth dose measurement in water with calorimetry and ionometry compared to Monte Carlo simulation.
2.5D convolutional neural network for HPV prediction in advanced oropharynx cancer

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2ETH Zurich, Department Medical Physics in Radiation Oncology, Zurich, Switzerland
3Kantonsspital Aarau, Centre for Radiation Oncology KSA-KSB, Aarau, Switzerland

Introduction
In the present study, we aimed to predict HPV status of advanced OPC patients using computed tomography (CT) images with a 2.5D Convolutional Neural Network (CNN). We assessed model performance on two external datasets.

Materials & Methods
CT images and clinical data were retrospectively collected from our institution and from three datasets publicly available at The Cancer Imaging Archive (internal dataset: n=151, OPC Radiomics: n=451; HN1: n=68; HNSCC: n=110). The OPC Radiomics collection and our hospital dataset were employed for model training, whereas the HN1 and HNSCC collections were used as independent test sets.

On each scan, a subvolume of size equal to the largest tumor in the training dataset was cropped, centered around the tumor. Then, 2.5D inputs were assembled by selecting the slice containing the largest tumor area per standard anatomical plane. The CNN architecture consisted of the first 45 layers of the 2D Xception model pre-trained on the ImageNet dataset, followed by two fully-connected layers. The model was trained using Adam optimizer and weighted focal loss as the cost function. Ten-fold cross-validation was applied to evaluate model training performance. At test time, soft majority voting was used to predict HPV status.

Results
The model achieved a final mean [range] area under receiver operating characteristic curve (AUC) of 0.83 [0.74-0.94] and accuracy of 0.76 [0.69-0.85] on the training dataset. After soft majority voting, AUC/accuracy values of 0.82/0.74 and 0.83/0.75 were achieved on the HN1 and HNSCC test sets, respectively.

Summary
Deep learning was successfully applied and validated in two external cohorts to predict HPV status of advanced OPC patients, proving the feasibility of CNNs to decode biological information present in CT images.

Appendix 1

<table>
<thead>
<tr>
<th>#Patients</th>
<th>Training Cohort</th>
<th>Test Cohort 1</th>
<th>Test Cohort 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>T3</td>
<td>151 (62.9%)</td>
<td>451 (74.8%)</td>
<td>662 (100%)</td>
</tr>
<tr>
<td>T4</td>
<td>100 (37.1%)</td>
<td>189 (31.4%)</td>
<td>100 (100%)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPV Status</td>
<td>Pos</td>
<td>Neg</td>
</tr>
<tr>
<td>Age</td>
<td>60.2 [47.2-75.7]</td>
<td>60.3 [53.0-81.2]</td>
</tr>
<tr>
<td>Sex</td>
<td>176 (76.6%)</td>
<td>55 (20.4%)</td>
</tr>
<tr>
<td>Stage</td>
<td>26 (11.4%)</td>
<td>61 (24.0%)</td>
</tr>
<tr>
<td>Tumor Stage</td>
<td>T1/T2</td>
<td>41 (27.5%)</td>
</tr>
<tr>
<td>Non-Tumor Stage</td>
<td>A0</td>
<td>29 (17.2%)</td>
</tr>
</tbody>
</table>

Table 1: Patient characteristics of training and test cohorts. T, N and overall stage correspond to AJCC 7th edition guidelines.
Figure 1: ROC curves of the two test cohorts (HN1 and HNSCC datasets).
Attention based deep 3d multiple instance survival models for oropharyngeal carcinoma patients

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4National Center for Tumor Diseases (NCT), Partner Site Dresden, Germany: German Cancer Research Center (DKFZ), Heidelberg, Germany; Faculty of Medicine and University Hospital Carl Gustav Carus, Technische Universität Dresden, Dresden, Germany, and; Helmholtz Association / Helmholtz-Zentrum Dresden - Rossendorf (HZDR), Dresden, Germany
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Introduction
Attention-based convolutional neural networks (CNNs) have the capability to use multiple parts of the same image to predict outcomes of interest. Especially in the domain of medical image analysis, where whole images are typically described by a single label but the identification of important image regions is unclear, this approach allows to combine competitively performing CNNs with enhanced interpretability of the decision-making process.

Materials & Methods
We developed risk models for the prediction of overall survival (OS) for 518 patients of a publicly available oropharyngeal carcinoma (OPC) cohort. Patients were randomly split into training, validation, and test cohorts (388/30/100 patients). A baseline Cox model using clinical information only and three attention-based CNNs using different likelihood functions were trained on multiple 3D instances of the pre-treatment computed tomography (CT) images. Subsequently, patients were stratified into groups at low and high risk of death using median cutoff values based on predictions determined on the training cohort. Model performance was measured using the concordance index (C-index) and differences between Kaplan-Meier curves were assessed by the log-rank test.

Results
The baseline Cox model achieved a C-Index of 0.22 and the CNN models based on the Cox, Weibull and Lognormal likelihood functions achieved C-indices of 0.34, 0.35 and 0.35, respectively, on the test cohort. All models stratified the patients into two risk groups with a statistically significant difference in OS. Attention scores between the multiple instances of a patient were similar, suggesting that all CT instances were equally important for the network decision.

Summary
We investigated the potential of attention-based multiple-instance learning for prediction of OS on an OPC cohort. Since all attention-based CNNs generated risk groups with significantly different OS based on imaging data alone, we consider this approach promising for future validation studies.
Appendix 1

<table>
<thead>
<tr>
<th>Method</th>
<th>Metric</th>
<th>Training</th>
<th>Validation</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cox</td>
<td>Baseline</td>
<td>C-index</td>
<td>0.29</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p-value</td>
<td>&lt;0.001</td>
<td>0.017</td>
</tr>
<tr>
<td>Cox</td>
<td>CNN</td>
<td>C-index</td>
<td>0.15</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p-value</td>
<td>&lt;0.001</td>
<td>0.003</td>
</tr>
<tr>
<td>Weibull</td>
<td>CNN</td>
<td>C-index</td>
<td>0.17</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p-value</td>
<td>&lt;0.001</td>
<td>0.008</td>
</tr>
<tr>
<td>Lognormal</td>
<td>CNN</td>
<td>C-index</td>
<td>0.17</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p-value</td>
<td>&lt;0.001</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Table A1: Performance of investigated models.

Figure A1: Kaplan Meier curves obtained by stratifying patients according to the median training prediction of each model.
V60 Efficient Monte Carlo modelling of the Imaging Ring X-ray system using neuronal networks

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Introduction
The Imaging Ring system (MedPhoton, Salzburg, Austria) is a versatile solution for image guided radiotherapy in proton and ion therapy centers. Full Monte Carlo (MC) simulations are slow. The option of partial precalculating of the system and using so called phase space files is cumbersome, time consuming and results in large file sizes (>5GB).
We present a workflow for efficient MC modelling, starting with a full MC model, a subsequent training of a neuronal network and its implementation and use as a fast and convenient particle generator for simulations.

Materials & Methods
GateRTion v1.0/Geant4.10.3p3 was used to create a fully detailed simulation of the X-ray head of the Imaging Ring system based on the manufacturer documentation, starting with the initial electron beam impinging the anode. The model was tuned to match experimental data such as HVL (Nomex, PTW, Freiburg, Germany), focal spot size (slit camera, PTW, Freiburg, Germany) as well as field size (Lynx, IBA dosimetry, Schwarzenbruck, Germany) measurements. Simulations were performed for 60, 80, 100, and 120 kV. Photons exiting the X-ray tube were stored in a phase space file. A conditional Generative Adversarial Network (cGAN) (pytorch-lightning v0.8.5, 3 layers, 400 neurons, RMSprop training function) modified from the gaga-phsp project \cite{1} was trained using this phase space data as input (batch size 10e4, 20 epochs). The cGAN was implemented into GATE and used as a particle source for MC simulations.

Results
HVL values agree well with experimental HVL data with maximum deviations of 0.4mm. Training required less than 3 hours using a GTX2070 (Nvidia, Santa Clara, US). 1e7 photons were found to be sufficient for convergence with good data reproduction (Figure 1).

Summary
Introducing a conditional GAN into MC simulations allowed to improve simulation efficiency as well as to reduce the cumbersome use of large phase space files.

Figure 1: Energy (a), lateral (b) and transversal (c) histogram of the simulated (real) and conditional GAN generated data (fake) of a 100 kV beam exiting the X-ray head.

References
\cite{1} Phys Med Biol. 2019 Oct 23;64(21):215004. doi: 10.1088/1361-6560/ab3fc1
Generating treatment plans from dose distributions on segmented CTs with deep learning: A feasibility study

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Introduction
Automated treatment planning – and knowledge-based planning in particular – are research fields in radiation oncology that are increasingly based on deep learning techniques. Most of these approaches aim to predict optimal dose distributions, which are then fed back into the treatment planning system to produce deliverable plans. In this study, we introduce a workflow that directly produces executable DICOM-RT plans from dose distributions for prostate cancer.

Materials & Methods
Segmented dose distributions of 418 prostate cancer patients treated with VMAT were selected as model input. The underlying neural network was designed as a 3D encoder-decoder with multiple decoding paths. Latent space manipulations were applied to mimic known geometric operations, such as rotation and projection to generate beams-eye-views for the control points of VMAT arcs. The dataset was split into training/validation/test sets comprising 300/50/68 patients. The model was trained to predict MLC and jaw positions and the meterset, i.e. MU, at each control point. In a preprocessing step the plans were standardized to a fixed number of 240 control points uniformly distributed over 360°.

Results
The model was capable of reproducing MLC/jaw positions and the number of MU with an average error of 3.1 mm, 5.6 mm and 1.3 MU, respectively. Backprojections of the MU weighted beams-eye-views showed good conformance when compared to the ground truth (Fig 1).

Summary
This model for generating executable DICOM RT plans via deep learning yielded promising results for VMAT treatments of prostate cancer, including predicted MLC and jaw positions and the MUs. In a next step the predicted treatment plans will be dosimetrically evaluated (in terms of DVH). The feasibility study lays the grounds for further improving the proposed network architecture and training process towards other treatment sites.

Appendix 1

Figure 1: Backprojections of the predicted plan (a), the original plan (b) and the resulting absolute error (c).
V62  AI-based multiorgan segmentation for personalized CT dosimetry

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Introduction
The evaluation of dose reduction methods in computed tomography (CT) requires scanner-specific as well as patient-specific information. The currently used computed tomography dose index (CTDI) does not fully meet these criteria. The effective dose, on the other hand, complies with these requirements when calculated directly from the CT image, and it additionally allows direct comparability between different imaging modalities. We aim to develop a concept for rapid dose determination based on neural networks to achieve the computational speed required in the clinical workflow. The determination of the patient-specific effective dose from a CT image will then be obtained by solving two sub-problems: multiorgan segmentation and dose simulation. Here, we focus on the first sub-problem.

Materials & Methods
For multiorgan segmentation, we use a U-Net convolutional neural network architecture, which takes a 2D slice of a CT image as input and gives binary segmentation as output. The training dataset currently consists of 140 CT scans with six segmented organs.

Results
Multiorgan segmentation has an accuracy of 83 % on the validation dataset. The accuracy is given as the mean intersection over union between the segmentation performed by the network and the ground truth. The missing 17 % most likely result from inaccurate edge segmentation and the underrepresentation of individual body regions in the training data.

Summary
We have successfully completed the first steps in establishing a concept for personalized dosimetry in CT. We have implemented an auto-segmentation algorithm based on a U-Net architecture. Through an improved training dataset, we aim to achieve multiorgan segmentation with all the necessary organs for calculating the effective dose. Currently, we are working on the generation of a training dataset to determine the 3D-dose distribution that is adapted to a GE Optima CT 660.
An MRI sequence independent convolutional neural network for synthetic head CT generation in proton therapy

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Introduction
An MRI sequence independent deep learning technique was developed and validated to generate synthetic computed tomography (sCT) scans for MR guided proton therapy.

Materials & Methods
47 meningioma patients previously undergoing proton therapy based on pencil beam scanning were divided into training (33), validation (6), and test (8) cohorts. T2, T1, and contrast enhanced T1 (CM) MRI sequences were used in combination with the planning CT data to train a 3D U-Net architecture with ResNet-Blocks. A hyperparameter search was performed including two loss functions, two group sizes of normalisation, and depth of the network. Training outcome was compared between models trained for each individual MRI sequence and for all sequences combined. The performance was evaluated based on a metric and dosimetric analysis as well as spot difference maps. Furthermore, the influence of immobilisation masks which are not visible on MRIs is investigated.

Results
Based on the hyperparameter search, the final model was trained with fixed features per group for the group normalisation, six down-convolution steps, an input size of 128x192x192, and feature loss. For the test data set for body/bone the MAE values were on average 82.9/236.4HU when trained using T1CM images, 79.8/216.3HU for T1, and 71.1/186.1HU for T2. The structural similarity metric (SSIM) ranged from 0.95 to 0.98 for all sequences. The investigated dose parameters of the target structures agreed within 1 % between original proton treatment plans and plans recalculated on sCTs. The spot difference maps had peaks at +/-0.2cm and for 98 % of all spots the difference was less than 1 cm.

Summary
A novel MRI sequence independent sCT generator was developed, which suggest that the training phase of neural networks can be disengaged from specific MRI acquisition protocols. In contrast to previous studies, the patient cohort consisted exclusively of actual proton therapy patients (i. e., “real world data”).

Appendix 1

Figure 1: Difference of dose volume parameters for CTV and PTV comparing the sCTs with the planning CT.
Session 18 I Young Investigator Forum:

V64 A method for assessing and predicting deformable dose accumulation uncertainty

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Introduction
To accurately accumulate dose from each fraction to a common geometry, deformable anatomical changes require complex anatomic correlations between repeated images. The infinite amount of solutions that exist to the ill-posed problem of deformable image registration (DIR) can provide different results, adding to a degree of uncertainty in dose accumulation. We propose a method to estimate this dosimetric uncertainty in deformable dose accumulation.

Materials & Methods
The proposed framework combines three components: a geometric DIR uncertainty map, the fraction dose gradient and a direction factor distribution (Fig 1). A patient-specific DIR uncertainty model was built on the first treatment fraction, by correlating magnitude differences of various DIR results at each voxel to the magnitude of any single reference DIR. Only the reference DIR was applied in subsequent fractions, and geometric DIR uncertainty maps were estimated by this model. For validation, a gradient-only (G) and a method without geometric uncertainty modelling (GU) were investigated. The estimated dose uncertainties were respectively compared to the reference dose uncertainty (DUref) when different DIRs were applied individually for fractional dose warping. This method was validated on one head-and-neck (H&N) and one non-small cell lung cancer (NSCLC) patient, each with 8/9 repeated CTs.

Results
Figure 2 shows the voxel-to-voxel differences between estimations and DUref for different structures. Over 95%/85% of non-zero dose voxels in the body are predicted within ±5% of the prescription for H&N/NSCLC case respectively, compared to 8%/66% when only dose gradient was used as estimation. The difference between estimations with (GMU) and without (GU) geometric modelling was marginal. Fractionation can mitigate but not eliminate DIR induced dosimetric uncertainty impacts.

Summary
The proposed approach is able to provide an accurate and efficient estimation of deformable dose accumulation uncertainty for both H&N and NSCLC treatments.
Fig1: Framework scheme.

Fig2: Difference of estimations (G/GU/GMU) to DU\textsuperscript{ref}. 

Joint Conference of the ÖGMP, DGMP and SGSMP
Deep learning for predicting gamma-ray interaction positions in LYSO detector

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3Inselspital Bern, Biomedical Research, Bern, Switzerland

Introduction
Organoids, stem-cell-derived three-dimensional tissue cultures, find increasing applications ranging from disease modeling to drug discovery and personalized medicine. These growing numbers of uses lead to strong demand for novel measurement capabilities.
In this abstract, we present the first steps of developing an on-chip PET system capable of imaging organoids. We evaluate the prediction of gamma-ray interaction positions with deep learning methods trained on simulated data.

Materials & Methods
For this purpose, we designed a Geant4 based Monte Carlo simulation of a tentative detection block consisting of three continuous LYSO crystals with silicon photomultipliers (SiPMs) added to multiple sides of the detector. We created a large dataset of light pattern images of a wide range of gamma-ray incidence positions and angles with the simulation. The dataset is used to train a Convolutional Neural Network (CNN) based reconstruction network learning the nonlinear relationship between gamma-ray interaction positions and their resulting surface light patterns. We also established a centroiding based baseline method for comparison with the deep learning based approach.

Results
We determined the optimal number of surfaces covered with SiPMs needed to predict the interaction position with various experiment runs. The experiments showed that some surfaces encode significantly more information compared to others. The best network achieved a mean average error (MAE) of 1.48 mm when trained on a dataset of 110,000 samples and tested on 14,000 samples. The baseline method achieves a MAE of 6.16 mm on the same test set.

Summary
The results indicate a promising direction for deep learning based gamma-ray interaction position prediction for a detector block of continuous crystals. With a larger dataset and an extensive hyperparameter search, the results will be further improved. In successive experiments, we will compare the results achieved with simulated data to experimental data.
Introduction
The application of radiation with ultra-high dose-rates in radiotherapy shows a sparing effect of healthy tissue compared to cancerous tissue. This so-called FLASH-effect is mainly studied by using electrons or x-rays. Radiotherapy using protons already shows benefits in the low dose-rate application compared to conventional treatment. Therefore, a combination of both the particle based sparing and the FLASH effect could further widen the therapeutic window. Here, we investigated the FLASH effect in proton treatment using an in-vivo mouse ear model.

Materials & Methods
For the experiment the right ears of 63 Balb/c mice were irradiated with 20 MeV protons at the ion microprobe SNAKE at the 14 MV tandem accelerator in Garching near Munich by using three dose-rates (3.7 Gy/min, 558 Gy/min and 55,800 Gy/min). Additionally we compared the FLASH-effect at 23 Gy and 33 Gy. For quantification, we measured the ear thickness, desquamation, and erythema for 180 days.

Results
No difference in the 23 Gy group for the different dose-rates was visible, whereas for the 33 Gy group it was significant. For 558 Gy/min we received a 57 % reduction of ear swelling and a 40 % reduction for 55,800 Gy/min compared to the conventional dose-rate of 3.7 Gy/min. Desquamation and erythema were reduced by 68 % and 50 %.

Summary
By using FLASH-dose-rates for low LET proton irradiation a tissue sparing effect can be achieved. This effect seems to be more significant with increased dose and was also observed at a dose-rate four times smaller than usually used FLASH-dose-rates (≥ 2400 Gy/min).
V67 Determination of the air-tissue interface in interstitial brachytherapy using an electromagnetic tracking system

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Introduction
In interstitial breast brachytherapy, an electromagnetic tracking (EMT) system prototype (Flexitron, Elekta Brachytherapy, Veenendaal, the Netherlands) can be used to measure the trace of the implanted catheters. Up to now, the length of these catheters inside the breast (between two plastic catheters fixation buttons at the patient’s skin) has been estimated using a CT scan since the button position cannot be determined by the EMT system. To allow button detection by EMT metal objects (washers/bushes) and magnets attached to the catheter on the skin have been investigated. The purpose of this phantom study is to quantify how accurate the position of those objects and thus the air-tissue interface can be detected.

Materials & Methods
EMT-data quantifying the position of a sensor, driving though the catheter, can be disturbed by metals or magnets. To determine the position of the air-tissue interface by using this disturbance, different types of metal objects and magnets with various geometrical dimensions were analyzed. The disturbance of the magnetic field leads to a gap of a certain length $G$ in the EMT data, which is bigger than the length $L$ of the metal/magnet, see figure 1. Using $G$ and $L$, the difference of the length $(\delta d = G - L)$ can be determined. The standard deviation of $\delta d$ reflects the accuracy of the interface position.

Results
The standard deviation of $\delta d$ for magnets, washers (steel) and the metal bushes are 0.4 mm ($N = 244$), 0.3 mm ($N = 320$) and around 0.4 mm ($N = 22$) for all geometrical dimensions, respectively. The magnitude of $\delta d$ is for all objects smaller than 5 mm. To minimize data loss, a small gap size is advantageous. The smallest gap size of $G = 4.5$ mm was obtained using magnets.

Summary
The detection of the air-tissue interface is possible with low uncertainties and can improve the quality assurance of interstitial breast brachytherapy. Magnets seem to provide the best results.

Appendix 1

Figure 1: Phantom with a catheter and the metal object/magnet on it (green). The red dots represent the EMT data with the gap $G$ around the metal object/magnet with the length $L$. 
Joint Conference of the ÖGMP, DGMP and SGSMP

V68 The role of uncertainties in jointly optimised mixed carbon/photon treatments

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Introduction
Joint and spatiotemporal optimization has recently been suggested to exploit radiation characteristics in mixed-modality treatments. Potential advantages are a better conformity of high doses and sparing of infiltrated healthy tissue by fractionation [1]. For biologically, jointly optimized (jOpt) carbon/photon treatments, we investigated the impact of treatment uncertainties. We compared jOpt plans to conventional separately optimized (sOpt) carbon boost treatments.

Materials & Methods
sOpt and jOpt plans were generated for a glioblastoma patient based on the total biological effect, \(E = -\ln(\text{surviving fraction of cells})\). Uncertainty scenarios were simulated assuming systematic range and fraction-independent random set-up uncertainties. The mean effect (mE) over the sampled scenarios and its standard deviation (stdE) were analyzed.

Results
Nominal effect distributions of the individual modalities are more heterogeneous for jOpt compared to sOpt (Figure 1), mitigating the sharp distal fall-off and associated uncertainty of the sOpt carbon beam, which correlate with locations of high uncertainty. Thus, stdE distributions analogously exhibit higher heterogeneity for jOpt (Figure 2). The substantially increased maximum carbon contribution in the boost target led to higher absolute stdE for jOpt (mean: 1.10, std: 0.83) compared to sOpt (mean: 0.45, std: 0.42) in the boost target.

Figure 1: Nominal total, photon and carbon effect, meanE and stdE over 52 treatments for jOpt and sOpt.
Summary

jOpt, utilizing the modalities’ distinct characteristics, results in more heterogeneous and patient-specific effect contributions compared to sOpt. This local effect redistribution makes jOpt more sensitive to uncertainties inside the boost volume while reducing uncertainty in OARs. Joint carbon/photon planning should therefore rely on distinct uncertainty analyses, and possibly use robust optimization for mitigation if necessary.

References

Intrafraction-motion-control in prostate cancer using catheter placing

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Introduction
For localized prostate cancer, primary external radiation (EBRT) is an equivalent treatment alternative to surgery. The dose required to control the tumor is applied in 38-41 fractions (normofractionated), in 20-21 fractions (moderately hypofractionated) or in 5-7 fractions (extremely hypofractionated).

In ultrahypofractionated radiation concepts, managing of intrafraction motion, i.e. the movement of the prostate during the treatment fraction, is mandatory due to longer treatment duration per fraction [1].

Material & Methods
A novel live tracking device (Raypilot Hypocath™), consisting of a transponder beacon and a detector panel was used. The transponder was positioned into the prostatic urethra using a urine catheter and a detector plate is mounted on the treatment table. This enables live monitoring of prostate motion during treatment and allows to halt treatment and reposition the patient if the prostate moves beyond a predefined margin. Standardized bladder filling and rectal emptying were performed before every treatment.

Results
Over the total treatment, vertical, longitudinal and lateral movement of the prostate was documented. Movement was primarily in sup/inf and ant/post direction. Average displacement increased with treatment duration in an almost linear fashion. Rapid and more pronounced prostate movements occurred infrequently. See fig. 1 for an example of a prostate movement during a single fraction.

Summary
The hypcath system is a reliable and easy to use tool to monitor prostate movements real time during ultrahypofractionated irradiation sessions. Thus, random errors of prostate localization can be detected, quantified and partially eliminated if the patient is repositioned after a predefined threshold has been exceeded.

Appendix 1

Figure 1: Prostate Motion.
References

Audiology 1

V70 Charakterisierung der binauralen Verarbeitung in komplexen, dynamischen Hörsituationen

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Hintergrund
Komplexe Hörumgebungen mit mehreren Schallquellen und Schallreflexionen an Wänden und Objekten begleiten uns im täglichen Leben, bereiten normalhörenden Personen aber wenig Probleme. Mit Hörstörungen nimmt die Fähigkeit, in solchen Situationen Schallquellen herauszuhören, stark ab, was zum Meiden sozialer Situationen und damit einer deutlichen Einschränkung der Lebensqualität führen kann. Die binauralen Verarbeitungsprozesse der Entmaskierung der Zielschallquelle im Hintergrundschall sind gestört. Dieser Beitrag beschäftigt sich mit den Möglichkeiten einer reproduzierbaren Bestimmung der Entmaskierung in dynamischen Hörsituationen mit bewegten Quellen bzw. einem bewegten Empfänger durch Kopfdrehung.

Methoden

Ergebnisse & Diskussion
Die Maskierung kann im Freifeld bei gut definierter Kopfposition auf 2-3 dB genau gemessen werden, wobei sich insbesondere bei bewegten Quellen Pegelfehler einzelner Lautsprecher und Reflexionen an der Apparatur als störende Amplitudenmodulation bemerkbar machen. Bereits bei wenigen 10 cm Abweichung vom Synthesemittelpunkt steigt der Fehler orts- und frequenzabhängig auf 4-5 dB an. Die binaurale Entmaskierung bewegter Quellen ist selbst bei langsamer Quellenbewegung entsprechend Fußgängergeschwindigkeit bereits gegenüber einer statischen Quelle reduziert, sowohl für einzelne Töne im Rauschen als auch für Sprache. Es kann davon ausgegangen werden, dass sich binaural sluggishness in realen räumlichen Hörsituationen negativ auswirkt.
Introduction
Our anatomy interacts acoustically with the sound field surrounding us. These effects can be described as head-related transfer functions (HRTFs) [1]. When calculating HRTFs, a high resolution of the 3D geometry of the pinnae is crucial in order to achieve listener-specific perceptive validity. In this article, we describe a parametrisation of the pinna geometry to break down the high-dimensionality problem when representing realistic pinna shapes.

Materials & Methods
The convex contours prominent in the pinna geometry are represented as Beziér curves (dashed green curves in Figure 1) and their control points (small spheres in Figure 1). To adapt the contours to a shape, the control points are transformed in an affine way, with vertices linked to the Beziér curves by a specific weighting. Vertices covering concave areas between the Beziér curves are deformed by so-called shape keys. For the evaluation, the model was created based on an average pinna (template) and adapted to a 3D model of an actual pinna (target). The model performance was evaluated in terms of geometric Hausdorff distance between the deformed template and the target.

Results
The introduced model controls a 20,000-vertices mesh with only 125 parameters (18 control points with six degrees of freedom each, 17 shape keys). The evaluation showed a good adaptation of the template to the target, with a geometrical error of 0.8 mm only.

Summary
We proposed a manually distortable parametric pinna model as a step towards reducing the dimensionality in 3D representation of human pinnae. The presented model successfully reduced the dimensionality of the pinna shape by a factor of approximately 160.

References
Figure 1: Parametric pinna model.


Im Beitrag werden Ergebnisse von Kindern aus unterschiedlichen Altersstufen präsentiert und mit der Lokalisationsleistung von Erwachsenen verglichen.
One of the advantages of virtual acoustics using higher order ambisonics (HOA) is the possibility to record auditory scenes in real environments, and reproduce them over loudspeaker arrays or over headphones. This is particularly important for hearing research, where using real environment recordings ensures a more ecologically valid evaluation of hearing devices. Since HOA produces spatial aliasing at high frequencies which makes device evaluations outside of the sweet spot difficult, alternatives to and modifications of HOA were investigated. These included the use of spatial decomposition of impulse responses and rendering (HO-SIRR, or AHO-SIRR) via combinations of HOA, vector-base amplitude panning (VBAP), and nearest speaker (NSP), as a way to ensure realistic beamformer outputs and interaural level differences outside of the sweet spot.

Impulse responses were recorded with a KEMAR manikin wearing hearing aid cases containing microphones, as well as with an Eigenmike array with 32 spherically arranged microphones. Recordings were made in two different rooms. 3D audio encoding and decoding was performed in Spat, a set of tools for 3D audio reproduction, with MAX, a visual programming language designed for audio processing.

Localization experiments were carried out, where normal-hearing subjects and hearing aid users had to localize a target speech sound that was coming from one of 32 directions, simulating restaurant or street environments. Results showed that the use of hearing aids increased the time required to localize sounds for the normal-hearing and half of the hearing-impaired participants. They also showed that hearing-impaired participants could not perceive elevation, with or without hearing aids, and that the type of hearing aid beamformers had a different effect on reaction time depending on the participant’s hearing loss.

In other studies with normal-hearing participants, hearing aid and cochlear implant recipients, the experimental task was to determine whether a target sound moved in their direction or went away from them. The stimuli varied in terms of reference distance, azimuth, distance offset, and hearing device processing. The results showed that age, hearing loss, reference distance, distance offset, and processing had a significant effect on the performance. Most participants struggled more when the target sound was far away. CI recipients were able to detect if a sound source was getting closer or moved further away. Background noise made the task significantly more difficult. Their overall performance was lower than that of individuals with mild to moderate hearing loss.

Acknowledgements
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Abstract for special session on Audiology at DGMP, Vienna, 19-21 September 2021
Precise synchronous processing of both ear signals is necessary for localization of sounds. For people with single-sided deafness (SSD) or bilateral deafness, fitting one or two cochlear implants (CIs) enables binaural hearing. The aim of this study was to investigate the impact of reverberation on localization ability in SSD users compared with a normal-hearing (NH) group.

Ten bilateral CI users (mean age: 52.3), seven CI users with SSD (mean age: 50 years), and 21 normal hearing (NH, mean age: 28 years) participated in the study. The tests were performed in an anechoic chamber under free-field conditions and in reverberation (simulation of the room acoustics of a lecture hall). Localization performance for pulsed broadband noise stimuli in the horizontal plane was determined for test angles between ±60°.

The median localization error in the free field was 14.8° in the bilateral CI group, 6.3° in the CI-SSD group, and 1.8° in the NH group. The localization error differed significantly between subject groups. In reverberation, localization performance deteriorated significantly by 1.5° in the NH group. In the CI groups, there was no significant deterioration in localization error in reverberation compared with the free-field condition.

All CI users with unilateral deafness showed a localization performance which was sufficiently accurate for everyday situations. While the CI group was on average worse than the NH group, two of the seven CI users achieved performance comparable to normal-hearing individuals. Due to an increased localization blur compared to the NH group and the higher variance of the measurement results in the CI groups, a significant deterioration of the localization performance in reverberation could possibly not be detected.
Effect of sound processor microphone characteristics on sound localization in noise in CI users

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Objective
Directional microphones are beneficial for speech understanding in noisy environments, but can adversely alter localization cues and thus degrade the localization ability of cochlear implant (CI) users. Our ongoing study aims to investigate the effect of the microphone characteristics ("Natural", "Adaptive", "Omni") used in the SONNET 2 CI sound processor on sound localization in noise in bilateral CI (BiCI) users as well as single-sided deaf (SSD) CI users. In addition, the bilateral benefit for sound localization in noise is to be assessed in these two groups.

Methods
To date, 5 BiCI users and 7 SSD CI users have been studied. Sound localization was assessed in an anechoic chamber. The names "Kerstin," "Stefan," and "Wolfgang" from the Oldenburg sentence test were used as target stimuli, each presented at two different levels and in two spectral shapes from one of 12 loudspeakers arranged in a full circle at an angular distance of 30° in random order. Multitalker babble was used as noise, presented from 8 loudspeakers positioned at an angular distance of 45° in the full circle.
For the BiCI users, sound localization in noise was measured bilaterally using the "Natural," "Adaptive," and "Omni" microphone characteristics, and unilaterally with the 1st or 2nd CI using "Natural", respectively. For SSD CI users, sound localization was assessed with CI using "Natural", "Adaptive" and "Omni", respectively, as well as unaided.

Results
For both BiCI users and SSD CI users, there was no significant effect of microphone characteristics on the RMS error of localization in noise (Friedman tests; BiCI: p=0.247, SSD CI: p=0.18). BiCI users had a significantly lower (better) RMS error with both CIs compared to only one CI (Wilcoxon tests; 1st CI vs. BiCI and 2nd CI vs. BiCI: p=0.043 each). Compared to the unaided situation, SSD CI users showed a significantly lower RMS error with CI with "Adaptive" (Wilcoxon test; p=0.028) and a trend of lower RMS with CI with "Natural" and "Omni", respectively (Wilcoxon tests; both p=0.063).

Conclusions
The preliminary results indicate that the three microphone characteristics implemented in the SONNET 2, "Natural", "Adaptive" and "Omni", are comparably suitable for binaural sound localization in noise for both BiCI users and SSD CI users. Both groups, BiCI users and SSD CI users, benefit from bilateral hearing for sound localization in noise.
Discharge criteria for radioligand therapy with $^{177}$Lu-PSMA-617

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Introduction
Following the German radiation protection regulation, patients treated with radioactive isotopes may only be discharged from nuclear therapy ward if exposure of the environment is below 1 mSv/a in a mean distance of two meters. Precise recommendations are currently made only for radioiodine-131 therapy (RIT). However, an activity or dose rate threshold for radioligand therapy with $^{177}$Lu-PSMA (RLT) is unfortunately currently not established, which has led to heterogeneous concepts of hospital discharge. National and international harmonisation is therefore required.

Materials & Methods
A dose rate threshold for release of patients treated with RLT was calculated based on the established recommendations concerning RIT. The maximum dose rate of 1 mSv/a was equated with the integral of the dose rate development from 0 to $\infty$. Therefore, a conservative half-life of 6.7 days was taken as basis. To calculate the release threshold for RLT in MBq a dose rate constant of $\left[\frac{T=0.00594 \ (mSv*m^2)}{(GBq*h)}\right]$ was used.

Results
A dose rate of 4.3 $\mu$Sv/h in a distance of two meters to the patient leads to an exposure of the environment not exceeding the threshold of 1 mSv/a. Activity and dose rate correspond by the dose rate constant. Therefore, a dose rate of 4.3 $\mu$Sv/h corresponds to an activity of 2.9 GBq.

Summary
A minimum inpatient stay of 48 h is recommended. Furthermore, patients may only be discharged when falling below a dose rate of 4.3 $\mu$Sv/h. If patients are treated several times per calendar year, the summed discharging dose rates must not exceed 4.3 $\mu$Sv/h. Caused by the multicycle concept of treatment, this has to be considered anticipating. The activity of 2.9 GBq applies only for oversimplified assumptions of an unshielded radiation source. However, due to the low $\gamma$-energy of $^{177}$Lu compared to $^{131}$I a general activity threshold for the discharge after RLT is not meaningful.
Contact shielding for patients in diagnostic radiology: comparison of SSK and SGSMP reports in the context of the actual debate

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Introduction

The traditional use of contact shielding for radiation protection of patients in x-ray radiology has been recently challenged by recommendations from several countries (e.g. Germany, U.K., Switzerland, USA). Using modern imaging technology, the benefit of shielding may indeed be negligible. It may even be counter-productive because of the potential appearance of artefacts or the necessity of exposure repetitions. The proposed change of paradigm focuses on collimation, optimisation, and other technical issues, which are less visible for the patients than the shielding aprons. This paradigm shift is still strongly debated as shown by the lively discussion at the ECR 2021. A EURADOS review recently pointed out the divergences among European national legislation. In parallel, representatives of several European associations (EFOMP, EFRS, ESR, ESPR, ESI, EURADOS, EADMFR) are currently working on a European consensus on this matter.

Materials & Methods

The most recent national recommendations and reports of the German Radiation Protection Commission (SSK) and the Swiss Society of Radiobiology and Medical Physics (SGSMP) were compared to the recommendations of other countries and discussed in relation to the ongoing debate.

Results

There is general agreement that other measures are much more efficient than patient contact shielding to protect both patients and professionals. However, the analysed documents differ in several recommendations, for instance concerning the need of eye lens protection in CT scans of the head, of abdomen protection for pregnant patients or of thyroid protection during CT scans of the chest.

Summary

The reviewed recommendations agree that the traditional use of patient contact shielding is in many cases no longer required. Active discussion is required among professionals to properly communicate its advantages and drawbacks to the patients.
Calculation of the relation between dose-length and dose-area product in conventional and cone-beam computed tomography

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Introduction
Due to its flexibility and low cost, cone-beam computed tomography (CBCT) has emerged as an alternative to conventional computed tomography (CT) for many imaging tasks. The radiation dose output for CBCT systems is usually measured in terms of the dose-area product (DAP), which is related to the incident dose. That of CT systems is normally measured in a dose-length product (DLP) in a phantom. Thus, the DAP and the DLP cannot be compared directly. A research project set up by the German Federal Office for Radiation Protection (BfS) under the project ID 3619S42462, aims at the determination of conversion factors for the DAP to the DLP for imaging tasks which can be performed with both systems. The final goal is to include the CBCT dose directly in the diagnostic reference levels of similar applications in CT.

Materials & Methods
Monte Carlo simulations are being performed on ten CBCT and two CT units using the ImpactMC software for the calculation of the DAP and the DLP. In parallel, experimental results are being collected in a second part of the project, which will be compared to the simulation results. The necessary simulation input parameters are obtained from different sources. For CT, source parameters are measured using the methods described in [1]. For CBCT, the spectra are derived from the high voltage settings and filtration, which are determined from the exposure parameters and specifications. The collimation has been measured with a dedicated test body.

Results
The simulations are ongoing, and the results will be presented at the conference.

Summary
An ongoing project is comparing the CT and the CBCT dose measured as a DLP and a DAP, respectively. This is being undertaken with measurements and simulations.

eP4  Evaluation of positioning in pediatric head CT examinations

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Introduction
The position of the patient influences both dose and image quality, as it affects the proper behaviour of tube current modulation and bowtie filter. This study focuses on evaluating the positioning of pediatric patients during head CT examinations.

Materials & Methods
A set of 138 pediatric patients with a head CT examination was evaluated. The data were analysed with the dose monitoring system DOSE (Qaelum, Belgium) installed in the hospital. Patient age, vertical and horizontal offset were obtained. The patients were categorized into 5 age-groups (G1:[0-1]y; G2:[1-5]y; G3:[5-10]y; G4:[10-15]y; G5:[15-18]y). A one sample t-test was used to evaluate if the mean offset of each group differed from zero. ANOVA and Tukey’s multiple comparison were used to evaluate if the mean offsets between the groups were different. A significance level of 0.05 was used.

Results
The average age was 7 years, ranging from 8 weeks till 17 years. Both the vertical and horizontal offset were not significantly different from zero for G3 and G5, but they were for G1 and G4. For G2, the horizontal offset was significantly different from zero, but the vertical offset not. The mean horizontal offsets between the age-groups were not significantly different, but mean vertical offsets were. The youngest age-group had a higher mean vertical offset (Figure 1). The offset was bigger than ±30mm for the vertical and horizontal offset in 5\% and 3\% of the cases respectively.

Summary
The positioning during pediatric head CT exams was evaluated and offsets from the isocenter were observed. While most offsets were rather small, large values were observed in some cases, especially for the age-group till 1 year old. This indicates the increased difficulty in positioning the very young and small patients.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{offset.png}
\caption{The mean and 95\% confidence interval of offset for the different age-groups.}
\end{figure}
Development of an acoustic lens for focus adjustment of high-intensity focused ultrasound

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Introduction
For the application of high-intensity focused ultrasound (HIFU) an acoustic lens is developed for focus adjustment of the transducer allowing easy and rapid treatment of extensive areas.

Materials & Methods
Simulations of the total acoustic pressure field and temperature rise of a HIFU application with and without an acoustic lens are created using COMSOL MultiPhysics (Fig. 1). The acoustic lens is simulated as a coupling medium using glycerol with an acoustic impedance different from water. For the experimental setup the acoustic lens is constructed as an attachment for the US transducer as a 3D model and realized with the 3D printer. A simple schlieren photography system is used to verify the actual shift of the focal point when the acoustic lens is applied.

Results
A comparison of the simulations shows a shift of the focal point when using an acoustic lens as well as the emergence of small minor maxima (Fig. 1). Experimentally the sound field can be clearly displayed with the help of schlieren photography, in particular the focal point can be easily recognized (Fig. 2). This is given for the setup without the acoustic lens as well as with the lens attached to the transducer.

Summary
The use of an acoustic lens to shift the focal point is simulated and verified experimentally. With further development, this technique offers the possibility of focus shifting and will facilitate tumor ablation with HIFU in the future.
Figure 1: Left: The simulated temperature rise and partial sound pressure using a HIFU transducer without an acoustic lens. Middle and right: The focal point is shifted when acoustic lenses with different refraction properties are simulated.

Figure 2: Visualization of the congruence of the simulated sound pressure and the schlieren photograph without the use of an acoustic lens.
**Introduction**

The electrometer NOMEX (PTW -Freiburg, Germany) has a negative polarity output, and thus a polarity change is not possible. Therefore, ionization chambers, calibrated with a positive polarity, cannot be operated under reference conditions. The following work investigates the influence of a negative polarity on the CT chamber 30009 (PTW-Freiburg, Germany) in a non-typical and a typical scenario.

**Materials & Methods**

At first, the chamber was positioned on a C-arm and dose measurements were performed free in air at a 120 kV tube voltage and an exposure of 3.78 mAs (steam shielded by a lead plate and unshielded - figure 1). Furthermore, the ionization chamber was placed on the bottom position of a CTDI-phantom, which was centrally positioned in a Definition AS open CT and an axial CT scanning with a collimation of 14.4 mm was acquired at 120 kV and 300 mAs. Each measurement was performed at least three times to minimize the influence of variations in energy output of the x-ray source. A UNIDOS electrometer with a positive polarity was used as reference and the relative difference in charge was compared against the NOMEX dosemeter for every single scenario.

**Results**

For the non-shielded C-arm scenario a systematic difference of about 5 % was observed (see table 1). This was significantly outside the variation of x-ray energy output (max 2 %, std.dev.: 0.5 %) and the specified uncertainty of 0.5 % of the electrometers. For the shielded C-arm scenario a significant difference was not observable. Similar results were found for the typical scenario of the CTDI measurement. Regarding these investigations a polarity change seems critical only if the stem lies inside the irradiated field.

**Summary**

A polarity effect was only seen when the steam was fully inside irradiated field. For these specific scenarios, the NOMEX electrometer should be used with care.

**Appendix 1**

*Figure 1: The CT ionization chamber positioned on the C-arm. Left: shielded with a lead plate. Right: unshielded.*
Appendix 2

Table 1: Relative comparison between positive (reference) and negative polarity (Nomex against UNIDOS). Minus indicates that the NOMEX dosemeter value was lower.

<table>
<thead>
<tr>
<th>difference in %</th>
<th>non-typical scenario</th>
<th>typical scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C-arm fully irradiated</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>C-arm pb-shielded</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Characterising complex treatment plans in intensity modulated radiation therapy – an approach for detecting untypical plans.

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Introduction
The increase in treatment plan complexity due to IMRT leads to a corresponding loss of transparency and comparability. The purpose of this work is to automatically detect treatment plans that are markedly different from typical plans of the same treatment entity.

Materials & Methods
We used 170 prostate cancer treatment plans (dual-arc-VMAT, 10MV, 2Gy fraction dose) to fit a 7D-multivariate normal distribution \(\mathcal{N}(x; \mu, \Sigma)\) with features:
- total MU,
- MU-weighted equivalent square field size,
- mean and standard deviation of MUs per degree gantry angle,
- mean and standard deviation of maximum leaf travel per degree gantry angle
- treatment time.

All mean and standard deviations are generated over all control point intervals. An optimized beam delivery emulator was implemented to estimate the treatment time out of DICOM-RTplan-files. All features were centered and normalized using mean and standard deviation of the relevant training set (thus \(\mu = 0\)). Rare treatment plans were determined by setting thresholds \(N(x_{0.1/2}; 0, \Sigma)\) with
- \(x_{0.1} = \sum_i \sigma_i v_i\)
- \(x_{0.2}(h) = h \cdot x_{0.1}\)
where \(v_i\) indicates the eigenvectors of the covariance matrix \(\Sigma\) with eigenvalues \(\sigma_i^2\). Plans with corresponding plan features \(x\) and \(N(x; 0, \Sigma) < N(x_{0.2}(h); 0, \Sigma)\) are defined as untypical (Region III). The hyperparameter \(h > 1\) defines the boundary between “still normal” (Region II) and “untypical”. We performed 5-fold cross-validation for several values of \(h\). For each cycle, 34 non-prostate plans (dual-arc-VMAT, 1.8-3.0Gy fraction dose) were classified additionally.

Results
Results are summarized in Tab 1. Decreasing \(h\) classifies more prostate plans as untypical but reduces the number of non-prostate cases in Region II clearly.

<table>
<thead>
<tr>
<th>(h)</th>
<th>34 prostate plans</th>
<th>Region I</th>
<th>Region II</th>
<th>Region III</th>
<th>34 non-prostate plans</th>
<th>Region I</th>
<th>Region II</th>
<th>Region III</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,0</td>
<td>Fraction of plans</td>
<td>62%</td>
<td>37%</td>
<td>1%</td>
<td>Fraction of plans</td>
<td>0%</td>
<td>14%</td>
<td>86%</td>
</tr>
<tr>
<td>1,8</td>
<td>Fraction of plans</td>
<td>62%</td>
<td>35%</td>
<td>3%</td>
<td>Fraction of plans</td>
<td>0%</td>
<td>10%</td>
<td>90%</td>
</tr>
<tr>
<td>1,5</td>
<td>Fraction of plans</td>
<td>62%</td>
<td>30%</td>
<td>8%</td>
<td>Fraction of plans</td>
<td>0%</td>
<td>5%</td>
<td>95%</td>
</tr>
</tbody>
</table>

Table 1: Rounded average of 5-fold cross-validation. \(N(x_{0.1}; 0, \Sigma)\) separates Region I and Region II, \(N(x_{0.2}; 0, \Sigma)\) Region II and Region III.

Summary
By adjusting \(N(x; \mu, \Sigma)\) we model the beam delivery characteristics of prostate VMAT plans to develop an additional automated check-up tool for plan approval. Untypical cases can be detected and further evaluated before treatment. The assumption that \(x\) is (approximately) normal distributed must be verified further.
Introduction
Since February 2021, Independent Dose Calculation (IDC) is partly replacing measurement-based patient-specific QA at the MedAustron Ion Therapy Center. This work presents the results of the dosimetric commissioning of the myQAiON (IBA Dosimetry) IDC system for a horizontal proton beam line (HBLp).

Materials & Methods
The agreement between Monte Carlo simulations and the measured baseline-data was checked with respect to beam ranges and beam optics, for 20 energies within the clinical proton energy range 62.4 - 252.7 MeV. The isocenter to detector surface distance (ISD) was increased towards the nozzle, leaving air gaps between 64.8 cm (ISD0) and 6.8 cm (ISD58). In addition the influence of range shifter was investigated. The beam model (BM) was calibrated in mono-energetic scanned fields and verified for various 3D targets in water.

Results
Simulated ranges were found to agree with the baseline measurements within ±0.2 mm, Bragg-Peak width within ±0.1 mm. Simulated spot sizes agreed within ±5 % to the baseline (Figure 1). Dose in reference conditions deviated from measurements by -0.3%±0.5 % in average. Point dose comparisons of 3D targets resulted in an average dose difference between IDC and measurements of +1.8 %, independently of the target size, energy or range shifter. Consequently, a 1.8 % scaling factor in terms of number of particles was applied to the BM (Figure 2).

Summary
Agreement between simulations and measured baseline data was found to be well within clinical tolerances. The dosimetric commissioning of the HBLp BM was a pre-requisite to start clinical commissioning in patient CT geometry.
Figure 1: Agreement of FWHM between simulated spots and baseline data for different airgaps without range shifter (RaShi).

Figure 2: Comparison between simulated and measured data for a spread out Bragg-Peak of a 3D reference dose distribution of size 8 x 8 x 8 cm centered at a depth of 15 cm.
Development of an online monitoring system for medical devices in radiotherapy

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Introduction
Medical devices are often operated in heterogeneous networks. In radiation therapy both, the medical devices and the network supporting them play a central role in clinical workflows. An approach how to read network traffic with the help of small computers including automatic notification in case of deviations is presented.

Material & Methods
Small computers achieve online analysis (Raspberry Pi) by picking up the network traffic through a mirror port on a switch. Such a port replicates the network traffic of a real medical device. The Raspberry Pi’s operate a network analyzer software (tshark, Open Source), which produces a file (pcap) that contains all information needed for the further analysis. These files are sent to a central analysis server where a software performs the analyses through algorithms developed based on clinical use cases (Fig. 1).

Results
The initial evaluation concentrates on the analysis of CT-scans and structure sets. The data extracted from DICOM headers provides insides into tube voltage current as well as the series instance UID, among other things. Therefore, it is possible to determine if the tube voltage complies with the nominal one or if the number of slices is in the correct range. Analysis of DICOM RT Struct data allows verification of contours (volume, existing but void, ...). In case of deviations, an E-Mail is sent. Analyses can be done within a short time such that notifications easily arrive before the next workflow step begins.

Summary
With the help of the presented approach, the network traffic of a radiation clinic with medical devices of different manufacturers can be analyzed automatically. More use cases are currently implemented.

Appendix 1

Fig. 1: Infrastructure used for recording the data stream with small computers.

References
[1] syngo.via, Siemens Healthcare AG ©
[2] RayStation, RaySearch Laboratories ©
Establishing CT reference dose levels in radiotherapy planning

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Introduction
In CT scans, automatic notifications have to be triggered if reference dose levels are exceeded. Diagnostic reference levels published by the German federal office for radiation protection BfS are based on values from X-ray diagnostics. They specify expected dose levels and scan lengths for scans of various body regions and now need to be transferred and adapted to CT scans for radiotherapy planning.

Materials & Methods
Using CT data of a representative patient collective in radiotherapy classified by different scan protocols, dose variables volume CT dose index (CTDIvol) and dose length product (DLP) were analyzed retrospectively. Additional measurements were performed with the CTDI and Alderson phantoms. Based on these measurements, weighted CTDI values and DLPs were calculated, taking into account in-house and standard scan lengths.

Results
The values determined from the phantom measurements with standard scan lengths show good agreement with the data from BfS. However, there are deviations from expected values in the patient data, particularly from head and neck (H&N) and pelvic scans. A more detailed analysis showed that adding positioning aids and including shoulders in CT scans of the H&N region, which is needed for radiotherapy planning, caused increased levels (Fig. 1). In brachytherapy patients, an on average rather corpulent build of patients lead to increased levels (Fig. 2).

Summary
Based on the phantom measurements and the comparison with the BFS requirements for diagnostic scans, it was shown that specific values should be defined for CT scans for radiotherapy planning. To establish similar reference levels for radiotherapy we suggest to use the 75th percentile of dose levels from patient data in accordance with the definition of diagnostic reference levels published by BFS.

Appendix 1

Fig. 1: CTDIvol as a function of scan slice (H&N scan)
Fig. 2: CTDI$_{vol}$ as a function of patient diameter
Investigation of the robustness of the wide field array calibration

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Introduction
Detector arrays are widely used for machine or patient quality assurance in radiotherapy. The response of the individual detectors in an array must be calibrated to account for response variations among the whole detector array. These response variations occur due to manufacturing tolerances of the array components, or can be introduced by the regular exposure of the array to ionizing radiation. The Wide Field Array Calibration developed by Sun Nuclear Corp. allows the regular calibration of the array in an open beam of a clinical linear accelerator. This study investigates the robustness of the method regarding setup errors introduced by the user.

Materials & Methods
The Wide Field Array Calibration processes 6 array measurements of an open beam, whereby different detectors are brought to identical measurement positions. Then the algorithm can isolate beam inhomogeneities from response inhomogeneities to produce a matrix of correction factors. Typical setup errors were introduced to evaluate the robustness of the method: The array was set up at a Varian TrueBeam linear accelerator and misaligned by up to 2 mm, the Gantry by up to 2°, and the array tilt by up to 1°. Furthermore, the dependence of the method on beam quality and field size was evaluated. The resulting correction factors were compared to those produced by a reference setup, in which no intended errors were introduced.

Results
The correction factors affected by misalignments were within 0.3 % of the reference values. Beam quality variations from 6X to 6FFF and 15X can cause a deviation of up to 1.2%. Varying the field size from 10x10 cm² to 30x30 cm² causes a deviation of up to 0.4 %.

Summary
The Wide Field Array Calibration is robust with regards to typical setup errors. The manufacturer’s recommendation to perform a separate calibration per energy and field size was confirmed.
eP12 Specialised Winston-Lutz-Test to quantify the geometrical accuracy of single-isocenter multi-metastatic stereotactic radiotherapy

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Introduction
In the past, stereotactic radiotherapy treated multiple lesions sequentially. Nowadays single-isocenter multi-metastasis therapy is becoming increasingly important. This method requires an enhanced level of accuracy and quality control, since geometrical mismatch can lead to significant underdosage of individual metastases, specifically at distance from isocenter.

Materials & Methods
In the course of this requirement, a dedicated phantom, the MultiMet-Winston-Lutz Cube (Sun Nuclear Corp., Melbourne, USA) with 6 internal tungsten-carbide spheres (1 isocentric and 5 off-axis), was used. In analogy to the Winston-Lutz test, 10 non-coplanar MLC-based fields whose apertures enclose the spheres as square fields (2x2 cm²) are irradiated. The spherical centroids are reconstructed with respect to the MLC field boundaries and are compared to the nominal positions to quantify the positioning and imaging accuracy in a single-isocenter multi-metastasis treatment. The suitability of such a phantom was tested on a Varian Clinac iX.

Results
The MultiMet-Winston-Lutz Cube can be used either standalone or as insert in the Sun Nuclear Stereophan. Positioning of the phantom is achieved according to the external lasers and may be corrected using the linac’s imaging system (kV/MV or CBCT). However, due to the limited degrees of freedom and accuracy of the Clinac IGRT couch, a 6DOF table is recommended. The analysis of the images shows the high sensitivity of the system to mispositioning of the phantom, as well as to the size of the isocenter sphere. This effect maximizes for the sphere with the largest distance to the isocenter, while the highest accuracy is achieved for the central sphere.

Summary
The presented Multi-Mets Winston-Lutz test is a helpful method to quantify the geometric accuracies of a linear accelerator in the treatment of multiple brain metastases. Additional care should be taken with regards to off-centric targets and identified inaccuracies should be considered in the definition of PTV margins.
Introduction
A prototype system for MR-integrated proton therapy (MRiPT) with an in-beam MR scanner is currently under investigation at our facility. The commissioning thereof requires an accurate beam model, a 3D map of the full static magnetic field (MF) of the MR scanner and consideration of their interaction. This work describes measurements of the proton beam, the MF and beam modeling performed to set up a proton beam model for the MRiPT prototype system.

Materials & Methods
Measurements of central proton beam spot sizes in air at 10 distances from the beam isocenter (between -15 and 54 cm) and integral depth-dose profiles (100 to 226 MeV) in water were obtained without MF using a scintillation detector and a water phantom with a Bragg peak chamber, respectively. A beam model was fitted to these measurements by utilizing an automated regularization-based optimization process. A 3D magnetic field map of the 0.33 T open MR scanner was acquired using spatially resolved Hall probe measurements.

Results
In the absence of the MF, the optimized beam model reproduced the measured beam spot sizes in air with an error <0.5 mm for 100 – 226.7 MeV and depth dose curves in water with an error <0.1 g/cm² for 100 – 226.7 MeV. The magnetic field measuring approach delivers reproducible results with high accuracy and an uncertainty <±5 mT.

Summary
A proton beam model for the MRiPT prototype system without MF was established and a high-precision method for mapping the 3D MF of the MR scanner was developed. The MF map and the beam model will be used to establish an experimental treatment planning system providing a correction algorithm accounting for the influence of the MF of the MR scanner on proton beams. Further investigations are necessary to validate the beam model in the presence of the MF.
Investigation of dosimetry gel fractionation effects for end-to-end tests of complex MR-guided treatment scenarios

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Introduction
In MRgRT, inter-fractional anatomical changes are compensated by online treatment plan adaption. Due to the complex procedure, end-to-end tests with dedicated phantoms have to be performed and employing PAGAT polymer dosimetry gel (PG) allows measuring the 3D dose distribution. However, fractionated irradiation poses additional challenges as it alters the PG response. This study investigates the fractionation effect of PAGAT PG for application in an anthropomorphic pelvis phantom (ADAM-PETer)[1].

Materials & Methods
A set of PG-containers was irradiated under reference conditions with 2, 4 and 6Gy at a clinical MR-Linac (Viewray, USA) applying different fractionation schedules: (A) a single fraction (standard method), (B) 5 equal fractions and (C) a fixed fraction size of 1Gy with 10 minutes between each fractions. For each set, a dose-to-R\textsubscript{2}-relaxation rate calibration curve was generated. One additional PG-container was partly irradiated in 5 fractions of 1Gy within a water-filled cylindrical phantom. Finally, the ADAM-PETer phantom inserts were adjusted to perform PG measurements within the prostate and rectum and a treatment was planned delivering a dose of 5Gy in 5 factions to the center of the prostate.

Results
A higher PG response (2 % R\textsubscript{2}-increase at 6Gy, up to 15 % dose-difference) was found for the partly irradiated PG container for fractionation schedules B and C as compared to the standard method A (figure 1), which leads to a better agreement of measured and planned dose (figure 2). Schedule A and B will be applied for dose calibration when applying the planned ADAM-PETer experiment.

Summary
A good agreement of measured and planned dose was found, if PG calibration is performed with the same fraction schedule as the irradiation experiment. These findings will be applied to implement an already planned end-to-end test of a fractionated adaptive MR-guided treatment using the ADAM-PETer phantom.
Figure 1: Calibration curves generated using PG irradiations at reference condition with three different fractionation schemes: (A) a single fraction (standard method), (B) five equal fractions, and (C) a fixed fraction size of 1 Gy.

Figure 2: Dose profiles (a) of the planned dose and the three measured PG dose maps generated using calibrations A-C through the partly irradiated PG container (red) as depicted as the green arrow in (b) showing the CT image used for treatment planning overlaid with the planned dose distribution.

References
eP15 Implementation of a dedicated RT setup in MRI for head and neck tumor patients

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Introduction
In diagnostic imaging, mainly the image quality is addressed while additional geometric accuracy is needed for MR-based radiotherapy treatment planning. MR-CT registration accuracy and signal to noise ratio (SNR) can affect treatment planning. Especially the correct flex of the neck in the Head-Neck-Region (ENT) might influence the registration quality. Therefore, a dedicated MR-RT-setup for radiation planning in the ENT-region was implemented.

Materials & Methods
The planning images are acquired with a 1.5 T MRI-scanner. In addition, an inhouse build system for immobilization in treatment position is used. It consists of a flat tabletop and an MRI compatible mask-holder, that allow positioning exactly in RT-position in the MR (Figure 1). The SNR of the RT-setup was compared to the diagnostic setup for six patients; the obtained rotation angle after the MR-CT registration was quantified. Results from more patients will be presented at the conference. Sequence protocols were established according to RT-requirements.

Results
The mean SNR of the RT-setup was lower at the centre but similar to the diagnostic-setup at the edges closer to the coils. Nevertheless, the MR images in the RT-setup are suitable for clinical requirements. The needed registration mean-xyz-angles between RT-setup and CT were 0.49°±0.64°, -0.17°±0.65°, 1.15°±0.14°, between diagnostic-setup and CT 3.48°±1.77°, 0.11°±1.53°, 1.31°±0.93°. The developed protocol for the ENT-region includes a T2-TSE-DIXON and two T1-VIBE-DIXON, pre and post contrast agent. Additionally, an automatically sorted 4D-STARVIBE and a temporal 4D-GRASP-VIBE are acquired to gather 4D-images and view the contrast agent influx, and a diffusion-weighted-image.

Summary
The RT-setup with dedicated RT-protocols can ensure identical anatomy between MRI and irradiation thus could influence the registration inaccuracy. Dedicated RT-protocols can offer additional 4D-information that could show moment due to e. g. swallowing.
Introduction
In this work, an in-house developed phantom used in MRgRT for the validation of isocentre-alignment between MR and treatment device was further optimized. As the water-filled phantom holds a metallic sphere for radiation attenuation, MR image distortions occur due to magnetic susceptibility differences. The aim of this work was the quantification and reduction of these artefacts by dissolving salts in the water-filling for susceptibility adjustment.

Materials & Methods
The cubic phantom is 3D-printed including a grid for positioning with MRI. The phantom is used for isocentre-alignment tests by measuring the centre of a metallic spheres’ attenuation with radiochromic films attached to the beam exit side of the phantom. The spheres’ susceptibilities were measured using a MPMS®-XL magnetometer. Accordingly, suitable salts (CuSO₄, MgCl₂) for susceptibility adjustment of the water-filling [1] were defined and MR measurements (0.35T, 1.5T and 3.0T) were performed with different salt concentrations using clinical TrueFISP and TSE sequences. The extents of the susceptibility artefacts were calculated using a double gradient echo sequence to generate distortion maps [2].

Results
Distortions in the MR images (0.35T, 1.5T and 3T) were reduced to a minimum for all three metallic spheres (measured susceptibilities in Table 1). For Inermet®, maximum distortions could be reduced by up to 52 % (85 %, 81 %) at 0.35T (1.5T, 3T) by dissolving 3.0 g/l MgCl₂ (200 g/l CuSO₄) (Fig.1).

Summary
Susceptibility adjustment of the water-filling by dissolving salts allows the reduction of susceptibility-induced artefacts. Decreasing maximum distortions with increasing salt concentration were found for three different metallic spheres.
Fig. 1: Exemplary distortion maps (left) of Inermet® and CuSO₄ (1.5T) and the according maximum distortions measured as a function of the concentration (right).

Table 1: Comparison of the spheres’ densities and magnetic susceptibilities measured with a magnetometer.

<table>
<thead>
<tr>
<th>Sphere material</th>
<th>Density [g/cm³]</th>
<th>Susceptibility χ / [10⁻⁶]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>8.96</td>
<td>-9.01 ± 0.12</td>
</tr>
<tr>
<td>Lead</td>
<td>11.34</td>
<td>-16.40 ± 0.29</td>
</tr>
<tr>
<td>Inermet®</td>
<td>18.0</td>
<td>94.30 ± 0.17</td>
</tr>
</tbody>
</table>

Joint Conference of the ÖGMP, DGMP and SGSMP

eP17 Proton PBS delivery within the treatment volume of an in-beam MR scanner

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Introduction
The magnetic fringe field of an in-beam MR scanner integrated with a proton pencil beam scanning (PBS) beamline needs to be taken into account for accurate dose delivery of IMPT plans. This work investigates corrections to proton pencil beams when delivered in the treatment volume of an in-beam MR imager.

Materials and Methods
Monte Carlo (MC) simulations using TOPAS version 3.5 were applied to model the PBS dose delivery to the treatment volume of an in-beam MR imager at the PBS beamline at OncoRay. A 3D map of the full magnetic fringe field of the 0.33 T (vertical field) open MR imager was mapped out and incorporated in the MC simulations. To estimate the distortion of the beam profile in the treatment volume, the delivery of a 10x10 cm² spot pattern for beam energies of 100, 150 and 200 MeV was simulated in air at the MR isocenter positioned 57 cm downstream of the beam isocenter. The energy-dependent mean lateral deflection was used to correct the beam delivery by a rigid shift of the field.

Results
Lateral deflections of 32.2 mm (100 MeV), 25.6 mm (150 MeV) and 22.2 mm (200 MeV) were observed for all spots. When correcting for these deflections, the mean error in the spot positions were 0.9 ± 0.2 mm (100 MeV), 0.5 ± 0.6 mm (150 MeV) and 0.7 ± 0.1 mm (200 MeV), with maximum differences of 2.0, 2.3 and 0.9 mm, respectively. No distortion of the spot pattern was found.

Conclusions
A submillimeter error in the spot position at the isocenter of the in-beam MR scanner can be achieved for a 10x10 cm² field when applying energy-dependent corrections in the delivery of the spots. Ongoing research will consider larger fields sizes and corrections needed to account for the beam stopping in water.
eP18 Reproducibility of dose measurements and influence of recombination and polarity correction for output factor measurements at a 0.35 T MR-Linac

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Introduction
This project aims to perform output factor measurements in small photon fields in the presence of magnetic fields. As a first step, the reproducibility of dose measurements at a 0.35 T MR-Linac and influence factors on charge collection in the detector were investigated.

Materials & Methods
Experiments were performed at a 6 MV photon beam of a MR-Linac (ViewRay MRidian) with PTW PinPoint3D (31022) detector, placed inside a water phantom (PTW BEAMSCAN MR). The detector axis was orientated parallel to the magnetic field and perpendicular to the beam. All values were measured at a depth of 5 cm and 85 cm source-to-surface distance.

Results
Repeated measurements of detector reading on the same day showed a reproducibility better than 0.22 %. Dose variation per monitor unit on different days varied within 0.99 % uncertainty. Using the two-voltage method, the recombination correction factor, $k_s$, was found to be 1.0045 and 1.0051 for 10x10 cm$^2$ and 1.7x1.7 cm$^2$ field size, respectively. Measurements at opposing polarizing potentials led to the polarity correction factor, $k_{pol}$, of 0.9988 ($\pm$ 0.0004) and $k_{pol}$ = 0.9990 ($\pm$ 0.0003) for 10x10 cm$^2$ and 1.7x1.7 cm$^2$ field size respectively.

Summary
The presented work was performed to investigate the set-up for output factor measurements and to determine the impact of potential influence factors. Preliminary results showed that recombination and polarity corrections were independent of field size. The output variation of the MR-Linac varied by 1 % from day to day, but only less than 0.22 % during one measurement session. Therefore, measurements of small fields and reference fields at the same day are necessary for further output factor measurements.

Acknowledgements
“This project 19NRM01 MRgRT-DOS has received funding from the EMPIR programme co-financed by the Participating States and from the European Union’s Horizon 2020 research and innovation programme”
eP19 Concomitant field compensation for double diffusion MRI encoding using oscillating gradients

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Introduction
In diffusion-weighted MRI, usually strong gradients are used to obtain information about diffusion processes within a sample. These gradients generate concomitant or Maxwell fields, which may cause severe artifacts [1, 2]. In this study, we present a proof-of-concept demonstration of concomitant field compensation in the context of double diffusion encoding (DDE) using additional oscillating gradients with the aim of measuring microscopic tissue anisotropy.

Materials & Methods
A DDE sequence was adapted for concomitant field compensation (Figure 1). An elongated water phantom was used in all measurements. The strength of the bipolar diffusion-weighting gradients was increased to quantify the effect of the concomitant fields and the respective compensation on image magnitude.

Results
As shown in Figure 2 (a), concomitant field-induced artifacts worsen with distance from the isocenter as expected by theory. As seen in (b), the oscillating gradients remove the concomitant phase and no related artifacts are visible.

Summary
It could be shown that the usage of oscillating gradients is an efficient tool for the removal of concomitant field-induced artifacts for DDE. The oscillating gradients generated a negligible diffusion weighting (\( \frac{B_{osc}}{B_0} = 0.01 \)). Thus, the desired diffusion image was well conserved. In conclusion, the proposed method can enhance image quality whenever large gradient strengths and field-of-views cause concomitant field-related artifacts in DDE.

Appendix 1

![Figure 1: Bipolar diffusion-weighting gradients (blue) are used for double diffusion encoding (a), while oscillating gradients (green) are implemented to null the induced concomitant fields (b).](image)
Figure 2: Acquired magnitude images without concomitant field compensation (a), with compensation (b), and without diffusion weighting as reference (c).

References
Introduction
Magnetic Resonance Imaging (MRI) is increasingly used in radiotherapy planning due to the wide range of soft tissue contrast, which facilitates the differentiation between tumor and surrounding tissue. These contrasts can be tuned by a vast variety of MR sequence parameter sets (SPS), which directly affect image quality parameters like signal- (SNR) or contrast-to-noise ratio (CNR). Depending on the sequence and clinical objective, these SPS can include up to 30 individual parameters. The aim of this work is to develop a Software tool for the optimization of MRI sequences with regard to the applied SPS for SNR and CNR.

Materials & Methods
First, a model to predict the quality parameters (SNR/CNR) depending on the applied SPS was developed and trained. For this, training data sets were acquired at a 1.5 T MRI (Sola, Siemens) with a dedicated phantom with in-house fabricated anthropomorphic contrast inserts of different concentration of agarose and Ni-DTPA. For this, measurements with either fixed bandwidth or number of signal averages (NSA) were used to generate a total of 40 different SPS-combinations. For SNR determination the SNR_{double} method is used [1]. Then a generalized additive model (GAM) is used for regression which is based on spline functions.

Results
According to the physical dependency, SNR is expected to be proportional to \( \frac{1}{\sqrt{BW}} \) and \( \sqrt{\text{NSA}} \). The measured SNR data was compared with the physical dependency and the GAM predictions (Figure 1). The GAM predicts the given data with two independent parameters with a mean absolute error (MAE) of 0.6, and 3.2 for bandwidth and averages respectively.

Summary.
As a first step towards the development of an optimization tool for MR sequences, the GAM method showed a good agreement with the presented measurements. The next step is to develop and implement optimization methods with regards to SNR based GAM.
Figure 1: Measured SNR values calculated with $\text{SNR}_{\text{double}}$ method (blue), GAM results (orange) and the physical dependency (green) for Variation of one parameter (left: NSA, right: Bandwidth) with the other parameter fixed.

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Introduction
Phantoms mimicking organs or tissue offer objective quality control for the optimization of MRI protocols and serve as tools to prove the applicability of MRI-guided therapeutic procedures, e.g. in radiation therapy or surgery. The manufacturing and application mainly face 3 challenges: the adjustment of MR-parameters T1 and T2 according to the tissue properties, mechanical and biochemical long-term stability/reproducibility and MR-visibility. Phantoms based on polymers and elastomers along with 3D-printing technologies might be ideal candidates for corresponding materials. However, they feature mostly short MR-signal-decay and lack T1/T2 variation for mimicking organ-specific MRI-contrast. Here, we present the first results of a systematic MR-investigation on different silicone-based and Fused-Deposition-Modeling (FDM) materials with varying additives. We investigated MR-visibility with standard gradient-echo (GRE), spin-echo (SE) and pulse-sequences for Ultrashort-Time-Encoding (UTE), moreover T1- and T2-mapping. Examples of MR-images on manufactured phantoms are shown.

Materials & Methods
2 classes of polymer materials have been investigated using a 3T clinical MRI-scanner:
1.) Elastic polymers based on a 2-component poly-condensation or -addition process of a silicone-monomer and a crosslinking agent with varying mixture ratios, blended with different concentrations of jelly candle wax.
2.) Rigid FDM-printed cylindric samples, mainly based on Nylon and PLA with different additives mimicking bone tissue.

Results
The rigid FDM-printed materials could not be imaged using standard MRI pulse-sequences as GRE, SE and even UTE with optimized protocols for short TE.
Most of the elastic silicone-polymer materials and examples of phantoms can be visualized using MRI-GRE- and SE-protocols (fig.1a). A broad range of different T2-/T1-values was observed in quantitative mapping depending on mixing-ratios: 38ms<T2<171ms (fig. 1b); 273ms<T1<510 ms.

Summary
Silicone-based elastomers are well suited as phantom materials in mimicking soft tissue within MRI. Their T2-MR-contrast can be varied easily using different ratios of crosslinking-agent and basic silicone-monomer and additives like jelly wax.
**Figure 1a:** MR-visibility of a set of body compartment phantoms using a SGE-sequence (TE = 2.89 ms, TR = 80 ms; bw: 590 Hz/px; V3: -1.1 mm).

Left/top: Silicone-vessels at different size and section
Right/top: Silicone (KTV-Z 535) samples with coating and additve.
Right/bottom: breast soft PVC-phantom (plastisol).

**Figure 1b:** T2 parameter map (color encoded) of a set of silicone samples featuring different 2-component mixtures and add-ons of jelly candle wax.

Blue: 38 - 50 ms
Violet / red: 51 - 105 ms
Orange/yellow: 110 - 171 ms.
Patient specific collision avoidance CBCT trajectories for interventional radiology – a real time approach

**Introduction**

C-arm cone beam computed tomography (CBCT) has become a significantly important tool for interventional radiology. Kinematic constraints due to the patient size or additional medical equipment often happen during the intervention and cause collisions with the imager while performing a standard circular rotation [Fig. 1]. We propose a framework to design collision-free, patient-specific source-detector trajectories for the cases where circular CBCT is not feasible.

**Materials & Methods**

We simulated variety of possible trajectory combinations from short arcs while taking into account existing spatial constraints. The optimal arc combination is selected using simulations on a prior diagnostic CT volume which serves as a digital phantom for simulations. We proposed a heuristic search strategy which searches among the possible collision-free trajectories and localize the most informative areas in space which provide the highest image quality to reconstruct particular region of interests (ROIs). We used Feature SIMilarity (FSIM) index as the objective function to evaluate the image quality provided by different trajectories. The performance of our method was investigated using anatomical targets from Alderson-Rando phantom. Adaptive steepest descent projection onto convex sets algorithm was used as the reconstruction algorithm.

**Results**

Our proposed trajectories can achieve a comparable image quality in the ROI compared to the standard circular CBCT. A relative deviation less than 10% was achieved between the reconstructed images from our proposed trajectories and the standard C-arm CBCT. The whole trajectory optimization took approximately three to four minutes.

**Summary**

Our study is the first demonstration of the feasibility for the design of on-the-fly scene-specific, noncircular CBCT trajectories that are suitable to react to unforeseen collisions. This brings a significantly important clinical benefit for interventions where a 3D CBCT is otherwise not feasible due to unpredictable collisions.
Figure 1: Two example of collisions [1, 2]

References
[1] DOI: 10.1371/journal.pone.0245508
Introduction
Radiomics is an approach to extracting quantitative features from medical images to obtain potential information about the disease. Radiomics features are extracted from the segmented volume of interest. Identification of a robust segmentation method or recognizing those features that are reproducible related to segmentation variability is a challenge in radiomics. We assessed feature reproducibility on a publicly available dataset of lung nodules using several open-source and available segmentation methods.

Materials & Methods
Several semi- and fully-automatic segmentation approaches are applied to segment nodules in RIDER test-retest lung dataset. Grow-cut and thresholding algorithms as semi-automatic segmentation algorithms and NVIDIA AI assisted [1] and nnU-Net [2] as automatic segmentation models applied in 3D-Slicer open-source software to segment lung nodules. Radiomics features are extracted using PyRadiomics, open-source radiomics library written in python. The stable features are selected by calculating Concordance Correlation Coefficient (CCC>0.85).

Results
The results show that there are subsets of radiomic features which are stable towards different segmentation methods. Only features with high repeatability and high reproducibility should be used for training the predictive models. Automatic segmentations indicates higher repeatability for resegmentations. nnU-Net and NVIDIA automatic segmentations can be considered rapid and accurate methods of tumor segmentation.

Summary
Radiomics features are extracted and analyzed from the segmented lesion. Trustworthy volumetric computations rely on accurate segmentation. Lesion segmentation is done manually or using semi- and fully-automatic methods. Manual segmentation suffers inter- and intra-reader variability and time consuming. It’s crucial to utilize a segmentation method that creates more stable features as one of the steps toward standardization of the radiomic workflow. The results show that automatic segmentations are rapid and accurate. But visual inspection is still required after software processing, spatially for sub-solid tumors.

References
**ePoster-Session 3 | Precision Radiotherapy**

**eP24 Dosimetric evaluation of modern auto-planning solutions for radiosurgery of multiple brain metastases**

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**Introduction**  
In recent publications several popular treatment options for stereotactic radiosurgery (SRS) of multiple brain metastases were compared. Given the high degree of complexity of these cases, the inter-planner variability can vary to a considerable extent and affect the results more than the technique itself. In addition, parameters such as radiation device, dose grid resolution and evaluation platform can play an important role. The purpose of this study is to compare the plan quality of two modern auto-planning approaches while minimizing possible misleading differences as much as possible.

**Materials & Methods**  
The employed treatment planning solutions were Brainlab Elements - Multiple Brain Mets SRS-version3 (MBM) and Varian- HyperArc- Eclipse16.1 (HA). The main difference between both systems is the treatment technique. HA utilizes RapidArc-VMAT and MBM depends on multi-aperture dynamic conformal arcs. Similarities include jaw tracking and using a single isocenter at the centroid of all targets. Furthermore, beam data is the same and origins from a Varian TrueBeam STx LINAC. Both systems can operate highly automated but were influenced by the same planner to ensure that prescription coverage was tolerable (98.5%±1 %) and no SRS dose constraints (QUANTEC) were violated. Ten cases with a total of 70 metastases (mean volume 1.1cc±0.9cc) were compared. The prescription of 20Gy was the same for all metastases.

**Results**  
Table 1 summarizes some of the most important SRS plan quality parameters. These include the Paddick conformity index (CI), the Paddick gradient index (GI), and volume dose metrics for the normal brain (whole brain minus targets). V5Gy is used to quantify the low dose spread and V12Gy is a well-established predictor for radio-necrosis. To get a better overview of all cases, a DVH-comparison for both techniques is plotted in Figure 1.

**Summary**  
We conclude that both solutions are able to generate acceptable SRS plan quality without significant planner interactions. Still, there are differences. HA achieves better conformity, with MBM providing the better gradient, which is also reflected in better V12. Due to the fact that the planning technique of MBM has fewer degrees of freedom than HA, this must be compensated for by the number of arcs and MUs, which is at the expense of the V5.
Figure 1: DVH comparison for HA- (blue) and MBM-results (red) of all ten multiple metastases cases. In favor of better overview, only whole brain and targets are plotted.

<table>
<thead>
<tr>
<th></th>
<th>CI-MM</th>
<th>CI-HA</th>
<th>GI-MM</th>
<th>GI-HA</th>
<th>V12-MM(cc)</th>
<th>V12-HA(cc)</th>
<th>V5-MM(cc)</th>
<th>V5-HA(cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>1.29</td>
<td>1.17</td>
<td>4.19</td>
<td>5.54</td>
<td>8.86</td>
<td>9.81</td>
<td>90.13</td>
<td>59.42</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>0.04</td>
<td>0.06</td>
<td>0.49</td>
<td>1.10</td>
<td>2.61</td>
<td>2.70</td>
<td>51.42</td>
<td>20.17</td>
</tr>
</tbody>
</table>

Table 1
Implementation and verification of a 3D neutron therapy planning software for a fission neutron source

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Introduction
The MEDical APPlication instrument MEDAPP at the research reactor FRM II in Garching is one of the last facilities providing Fast Neutron Therapy (FNT) for cancer treatment. The main goal of the work presented here is to customize treatment planning principles well known for other treatment modalities for the purpose of conformal radiotherapy with the mixed neutron-gamma-radiation field present at the reactor.

Materials & Method
MEDAPP is equipped with a motorized MLC and delivers a neutron-gamma-dose-rate of \( D \approx 0.74 \text{ Gy/min} \) at 2 cm depth in water at treatment position. Two approaches for dose deposition calculations are investigated. These are (A) an analytic approach using pencil beam kernels and (B) a Monte Carlo (MC) approach using MCNP.

To realize these approaches, the MATLAB based research treatment planning software matRad (www.matrad.org) was adopted so that its treatment planning infrastructure could be used while modifying the dose engine to different extents for the two approaches.

Results
While the investigated pencil beam kernels enable time efficient planning on patient CT-data, the considered MC approach provides higher flexibility in handling different material compositions (cf. figure 1).

For the validation of the dose calculations, dose measurements of the mixed field were performed in a water phantom. Using the two-chamber neutron dosimetry method, the measured neutron dose was found to be in good agreement with the calculated ones (cf. figure 2). Nonetheless, results depend on the field size. Fine tuning is necessary to reach a comparable accuracy for the gamma component.

Summary
The described set-up allows the user to perform treatment plan calculations for mixed neutron-gamma-radiation fields for research purposes.
Appendix 1

Figure 1: Example of neutron dose [Gy] distribution calculated using MCNP and visualized on CT data using matRad (target volume in black).

Figure 2: Comparison of measured and calculated neutron depth dose curves in water.
Introduction
Prior to patient irradiation, treatment plans and their dose distributions have to be verified by an independent procedure. To reduce time and workload required for dosimetric verifications, the aims of this project are the commissioning and the clinical implementation of a commercially available Monte Carlo system for independent treatment plan verification.

Materials & Methods
Measurement data of the machine commissioning process of two different linear accelerators is imported into ProSoma Core (MedCom) for beam model definition. The generated model is verified by comparing output factors, profiles (inplane and crossplane) and percent depth dose curves (PDDs) calculated by ProSoma Core to the original measurement data. Measurements as well as calculations were conducted in a water phantom for multiple field sizes and all available energies. Profiles and PDDs are compared in Gamma Analyses (2 mm, 2 %). In the next step, ProSoma Core is integrated into the clinical workflow to automatically evaluate patient treatment plans based on tumor-site-specific protocols.

Results
All generated profiles and PDDs satisfy the Gamma criteria. Output factors for small fields (aperture $\leq$ 1 cm) and larger fields (aperture $> 1$ cm) are within 5 % and 2 % agreement. The plan verification shows good consistency of the patient treatment plans.

Summary
A Monte Carlo software tool for individual and independent dose calculation was setup and commissioned. It can be used for independent dose calculation in general as well as for automated treatment plan verification, reducing time and workload previously required for dosimetric evaluations.
Multimodal imaging in ocular proton therapy treatment planning using RayOcular – first user's experience

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Introduction
In ocular proton therapy (OPT) the most commonly used treatment planning system is EYEPLAN [1]. The planning process is straight-forward: An eye model is created by fitting an eye model to tantalum marker positions, being sutured to the eye ball in close proximity to the tumor [2]. These positions are determined by orthogonal X-rays of the eye prior treatment. Dose calculation is based on a simple raycasting algorithm without explicit consideration of multiple scattering and material inhomogeneities [2].

RaySearch Laboratories has recently released RayOcular, a module in the treatment planning system RayStation, that supports OPT treatment planning.

Materials & Methods
Based on high resolution CT or MRI images, an eye model can be fitted manually to the provided 3D image data sets (fig. 1). This is accomplished by manipulating pre-defined structures in a physiologically meaningful hierarchy, like eyeball, cornea, lens, optic nerve and others individually. CT and MRI can be registered in parallel, support the modelling process and define the tantalum marker positions. Fundus composite or wide angle fundus images can be registered to the model.

Target delineation is either done ‘slice by slice’ in CT or MR images with standard contouring tools or by drawing the target base on the fundus image and setting the apex with a defined height like in EYEPLAN.

Actual treatment planning is performed in a similar way to EYEPLAN. Instead of a simple raycasting algorithm an efficient pencil beam model (PBA) is used for dose calculation.

Results
Eye modelling differs in various aspects from EYEPLAN but is comparable to the OCTOPUS treatment planning system workflow [3]. In contrast to the dose calculation in EYEPLAN the RayStation PBA takes the impact of wedges and tantalum clips explicitly into account and reproduces effects observed in measurements, such as scatter from wedges (fig. 1).

Summary
RayOcular is considered an appropriate tool and only commercial available system for multimodal treatment planning in OPT.
Appendix 1

Figure 1: RayOcular: Proton beam design window showing Beams-Eye-View (top left), 3D view of eye, beam, light field and wedge (bottom left), dose distribution on fundus (middle), dose volume histograms (DVH - top right), transversal CT slice with eye model and dose distribution (bottom right). A wedge is used to reduce the dose on the macula (magenta line in DVH). The wedge causes a long red hot spot, an effect that has been experimentally verified, but is omitted in the EYEPLAN dose calculation.

References
eP28 ITV or tumour tracking dose painting of NSCLC? A comparison of target coverage and out-of-target dose in proton treatments

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Introduction
Dose painting of a non-uniform dose distribution is challenging in the presence of organ motion, especially when it comes to proton therapy delivered with pencil beam scanning. We performed a comparative planning study to assess the potential of tumour tracking (TT) against the standard clinical approach based on the definition of an internal target volume (ITV).

Material & Methods
A single fraction treatment (2GyRBE) has been simulated for an advanced-stage NSCLC patient including a dose escalation by 17% of the clinical prescription to a region within the CTV with high-SUV on pre-treatment HX4-PET images (CTVDE). The free breathing tumour motion was evaluated on planning 4D-CT images to define an ITV as the union of CTVs in all breathing phases, covering 7mm target displacement. An additional 10 mm isotropic expansion has been applied to obtain the PTV. The TT plan was optimised on a single-phase CTV (60.6 cm³) using uniform 5mm planning margin. Both treatments were simulated for an increasing number of rescanning, up to 6 times.

Results
Target coverage (V95) for CTV and CTVDE, treated volume (TV, isodose 95%) and the out-of-target hot spot volume (HS, dose > 100 %) were calculated following the ICRU-50 definitions. While coverage was consistently higher than 98 % for both targets in all scenarios, a marked reduction of the treated volume was observed with tumour tracking. In these data sets, TVTT was at least 75 % less than the corresponding TVITV, with negligible out-of-target dose volume (max HS 1.5cm³) compared to HS>50 cm³ observed in ITV-based simulations.

Summary
Current treatment protocols based on ITV allow for dose painting even in the presence of organ motion. However, should the normal tissue dose be of concern, advanced techniques like tumour tracking, have the potential to substantially reduce the out-of-target dose and burden to organs-at-risk.
Dose distributions on sagittal plane cut. Dose expressed as percent of CTV prescription.
eP29 Variable relative biological effectiveness (RBE) in proton therapy of benign brain tumours

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6German Cancer Consortium (DKTK), Partner Site Dresden, and German Cancer Research Center (DKFZ), Heidelberg, Germany

Introduction
Currently, there is an intense debate on the need to consider a variable clinical relative biological effectiveness (RBE) in proton therapy. Here, a variable clinically derived RBE-model was applied in-silico to predict the risk for late radiation-induced brain injuries (RIBI) in benign brain tumor patients having undergone proton therapy.

Materials & Methods
In total, 23 patients with benign brain tumors of WHO grade I-II (meningiomas, pituitary adenomas and ependymomas), who received (adjuvant) proton radio(chemo)therapy between 2015 and 2017, were eligible for analysis. Dose and linear energy transfer distributions were retrospectively simulated and used to calculate variable RBE-weighted dose in brain tissue. The variable RBE-model was previously derived for RIBI observed after proton therapy in grade II-IV gliomas. RBE-weighted dose, dose-volume parameters and normal tissue complication probabilities (NTCP) were calculated in brain tissue within and outside the clinical target volume (CTV) using the variable RBE-model and the clinically applied RBE of 1.1.

Results
The average difference in maximum RBE-weighted dose between the variable and constant RBE-model was 12 Gy(RBE) [range: 7.9-15 Gy(RBE)] and 14.8 Gy(RBE) [8.9-19.2 Gy(RBE)] within and outside the CTV, respectively. In the same regions, values of 9.2 Gy(RBE) [5.8-12.6 Gy(RBE)] and 1.0 Gy(RBE) [0.2-3.2 Gy(RBE)] were obtained for the difference of the mean dose. Using the variable RBE-model the cohort average D4ml (minimum dose to the hottest 4 ml) and NTCP increased by 10.8 Gy(RBE) [7.4-16.0 Gy(RBE)] and 25.4% [0.6-53.4 %], respectively (figure 1).

Summary
A substantial increase in high dose and predicted RIBI risk was found in normal and normal-appearing brain tissue using the assumption of a variable RBE-model instead of a generic RBE of 1.1. After correlation of predicted with actually occurring RIBI on follow-up MRI scans, our results may help to verify and extend clinical RBE-models established for proton therapy of gliomas.
Appendix 1

Figure 1. The dose and linear energy transfer (LET) distributions for a meningioma patient (A-D) and a pituitary adenoma patient (E-H). For these two patients the simulated constant RBE weighted dose is shown in (A, E), the variable RBE weighted dose is shown in (B, F) and the simulated LET is shown in (C, G). The corresponding difference between the variable RBE weighted dose and the constant RBE weighted dose is shown in (D, H). On all images the contours of the gross tumor volume (GTV), the clinical target volume (CTV), the brain and the brainstem are shown.
**Introduction**

Stereotactic radiotherapy on LINACs requires precise geometric alignment of beams to the target for full coverage, especially for small fields or irradiation of multiple metastases using a single isocenter. Here, we analysed the accuracy of three matched LINACs.

**Materials & Methods**

The precision of the isocenter was analysed using the Sun Nuclear MultiMet-WL Cube at three LINACs (Elekta Synergy Agility, Elekta Versa HD) at 6 MV. Additionally, two non-coplanar 10-field stereotactic plans (PTV 1.89 cm³ and 0.34 cm³) were measured on each LINAC with the Sun Nuclear SRS-MapCHECK inside the StereoPHAN. Plans for the LINAC scoring the lowest average gamma values were corrected for isocentric shifts using a script [1] and re-measured.

**Results**

The distance of the field center and the isocentric target with the MultiMet-WL Cube was 0.66 mm on average and slightly above 1 mm for only one field (LINAC B). For Linac C (A) it exceeded 1 mm (1.5 mm) for five of 15 beams in the test sequence. Large deviations at LINAC A occurred at extreme couch angles only.

Average gamma for LINAC C was worst for both plans (Table 1). LINAC A had the lowest average gamma, because the plans used no large couch angles. Geometric deviations of LINAC C were successfully corrected with the script achieving gamma values comparable to the other two LINACs.

**Summary**

The geometric accuracy of the matched LINACs varied. A characterization helped identify the preferable LINAC for stereotactic treatments. Additionally, isocenter shifts, depending on the beam direction, could be corrected.

<table>
<thead>
<tr>
<th>Plan 1 (1.89 cm³)</th>
<th>Linac A, Versa HD</th>
<th>Linac B, Synergy Agility</th>
<th>Linac C, Synergy Agility</th>
<th>Linac C, corrected, Synergy Agility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.25</td>
<td>0.25 +/- 0.05</td>
<td>0.58</td>
<td>0.28</td>
</tr>
<tr>
<td>Plan 2 (0.34 cm³)</td>
<td>0.19</td>
<td>0.39</td>
<td>0.65</td>
<td>0.33</td>
</tr>
</tbody>
</table>

*Table 1: Average gamma (2 %/2 mm, global, absolute, 20% threshold). Exemplary uncertainty stated based on three measurements.*

**References**

Implementation and commissioning of a film dosimetry system for the investigation of SRS VMAT brain metastases treatment accuracy

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Introduction
This project deals with implementing and commissioning of a film dosimetry system. It illustrates potential pitfalls, sources of uncertainty, optimized workflows and comparisons to other dosimetry systems. Conducted in a bachelor’s thesis framework, it is part of a larger project regarding safety, accuracy and quality assurance for mono-isocentric stereotactic radiotherapy of multiple brain metastases.

Materials & Methods
Materials in this study include two types of radiochromic film, multiple ionization chambers and arrays, various phantoms, treatment planning system (TPS) and linac, flatbed scanner, commercially available evaluation software and in-house developed scripts for image processing. Scanner noise and position-dependent artifacts are investigated by scanning film pieces on 56 positions across the scanner. Triple-color-channel calibration is performed based on 13 dose levels throughout the recommended ranges. Film dose is evaluated in water tank and solid water phantom measurements, comparing film to ionization chambers, arrays and TPS. Additionally, film readout is compared to array measurements and TPS calculations for brain and brain metastases SRS VMAT plans. The results are verified in a cross-checking procedure with an independent, FDA-approved dosimetry center.

Results
The image processing script to compensate for scanning position artifacts results in a high agreement between film and array/TPS dose profiles. For VMAT plans, films show excellent agreement to TPS calculations (Gamma-Passing-Rates (2 mm, 2 %) consistently above 95 %). They prove their expected high spatial resolution and in contrast to SRS-dedicated arrays do not show any field size dependence of the measured dose. However, absolute dose determination is heavily reliant on a suitable calibration.

Summary
A method to setup and commission a film dosimetry system is presented. Despite higher cost and time investment, film dosimetry can be a valuable and important addition to conventional systems, especially for locating and quantifying high dose gradients in small volumes such as brain metastases.
eP32 End-to-End testing for stereotactic radiotherapy with a quality assurance phantom

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Introduction
An existing phantom [1] was evaluated for MRT geometry accuracy and usability on a non-coplanar X-ray imaging system. Also, stereotactic treatment plans were verified and the verification compared to a solution using an in-house phantom.

Materials & Methods
The phantom with an inhomogeneity insert (6 parallel bars: 3 MR capable, 2 bone-equivalent, 1 lung-equivalent, 1 chamber insert) was tested in MRT with and without distortion correction as well as on a non-coplanar X-ray imaging system and various CBCT systems. High positioning accuracy is essential, especially for small-volume target volumes with high single doses, such as trigeminal neuralgia. In addition, stereotactic treatment plans were verified with various small field chambers. These measurements were also repeated with a simple, in-house developed end-to-end phantom and then compared.

Results
In a CT-MRT comparison, the bars that are suitable for MR show well whether the distortion correction was active in MRT (Fehler! Verweisquelle konnte nicht gefunden werden.). However, the parallel bars are not well detected in the non-coplanar X-ray imaging system (> 3 mm deviation), which is why a displacement with stereotactic tolerances cannot be satisfactorily performed. The point dose values are in agreement with the expected values (< 1.5 % deviation) and also coincide with measurements using the in-house phantom.

Summary
The tested phantom is very well suited for individual tests. For an all-encompassing end-to-end test elements are still missing in the phantom in particular w.r.t. dedicated treatment systems such as for beam tracking. Developments are ongoing to address these limitations.

Appendix 1

Figure 8: CT (left) and MR (right) without distortion correction

References
eP33 Validation of end-to-end dosimetry methods for intensity modulated radiosurgery

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Introduction
Brainlabs treatment planning systems Elements Cranial SRS and Spine SRS enables highly conformal, intensity modulated SRS of cranial and spinal indications. The combination of high doses and small, modulated radiation fields requires a high degree of accuracy in target positioning and dose application.

The purpose of this study is to evaluate the SRS QA capabilities of the SNC SRS MapCHECK device and the MV Imager based software SunCheck Patient in comparison to film QA. By following an end-to-end approach, we test for precision, dose accuracy and usability including time requirements.

Materials & Methods
For the E2E-test we used phantoms (CIRS Ste2ev, SNC StereoPHAN) with spherical and organic target inserts that underwent every step in the treatment process.

The contouring of the intra and extracranial targets and organs at risk is based on a non-contrast T1- and T2-weighted 3D-MRI with a slice thickness of 1 mm. For dose calculation we acquire a high-quality thin sliced (1 mm) CT image.

The fundamental properties of SNC SRS MapCHECK Diode Detectors and the Varian MV Imager Panel used by SNC Patient such as reproducibility, small field resolution and geometrical accuracy are studied for 6 MV energy photon beams and compared to gold standard GAFChromic™ EBT3 films.

All dosimetric tests carried out using a Varian TrueBeam STx with a high definition multileaf collimator (HD120 MLC) and the external positioning monitoring system ExacTrac 6.5 by Brainlab.

The geometric accuracy of the CT and MRI fusion was checked by comparison of proper phantom inserts. The geometric accuracy of the dose applications was determined using the mentioned QA systems. By increasing the modulation degree of our plan, we tried to find limits and differences between the observed QA tools.

Results
As this work is part of an ongoing master thesis, final results will become available later this summer.
eP34 Clinical assessment of the SRS MapCHECK (Sun Nuclear)

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Introduction
The aim of this project was to establish gamma criteria recommendations for the SRS MapCHECK diode array. It was decided that a successful gamma criterion should detect any clinically significant errors while not being sensitive to clinically insignificant errors.

Materials & Methods
MLC misalignments ranging from 1 mm to 4 mm were introduced to treatment plans, which were then irradiated on a Varian Clinac (Varian Medical System, Palo Alto, USA) and compared to the unmodified treatment plans by measurement with the SRS MapCHECK in the StereoPHAN End-to-End phantom (both Sun Nuclear Corp., Melbourne, USA). Gamma criteria of 1 \%/1 mm, 1 \%/2 mm, 1 \%/3 mm, 2 \%/1 mm, 2 \%/2 mm, 2 \%/3 mm, 3 \%/1 mm, 3 \%/2 mm and 3 \%/3 mm were tested. The gamma analysis was carried out in the SNC Patient Software using a threshold value of 10 \%. Dose volume histograms were used to decide what magnitude error would be classed as clinically significant. \cite{1, 2, 3}

Results
It was established that a misalignment of just 1 mm can cause an under-dosage, which would result in the dose delivery being classed as a failure. The criteria constantly able to detect the misalignments of 1 mm were 1 \%/1 mm and 2 \%/1 mm. The 1 \%/1 mm criteria also flagged scenarios where no misalignments were introduced, so it was determined that this criterion was over-sensitive for this specific set up. Using 2 \%/1 mm, the SRS MapCHECK has shown to be successfully able to detect misalignments as small as 1 mm.

Summary
Due to 2 \%/1 mm never failing on a plan where no misalignment were added and was able to detect all misalignments which were added, it was concluded that the gamma criteria of 2 \%/1 mm should be used going forward in the patient specific QA programs for the SRS MapCHECK diode array.

References
Introduction
The ring tandem applicator with interstitial needles enables improved modulation of the dose distribution in HDR-brachytherapy cervical cancer treatment plans. Two optimization strategies were investigated using the Hybrid Inverse Planning Optimisation (HIPO) algorithm to reduce treatment planning time and standardize treatment planning.

Materials & Methods
The treatment planning system Oncentra Brachy (Elekta AB) v4.6 was employed with a microSelectron v3 afterloader (Elekta AB). All plans (n=21) were calculated for a 192Ir source (v2r, Elekta AB) using the TG43-formalism. The HIPO algorithm was employed to optimize dwell time distributions (DTD) according to two strategies: HIPO1 (applicator and sequential needle DTD) and HIPO2 (simultaneous applicator and needle DTD). Graphical optimization (GrO) was subsequently applied where dose constraints to OARs were exceeded. These were retrospectively compared to the clinically delivered plan (GrO alone).

Results

Figure 1 Sagittal slice of dose distribution a) GrO method; b) HIPO1) and c) HIPO2
Table 1 Fraction of total plan time for applicator and needles. Bold signifies a statistically significant difference.

<table>
<thead>
<tr>
<th>Optimisation method</th>
<th>Ring tandem</th>
<th>Needles</th>
</tr>
</thead>
<tbody>
<tr>
<td>GrO</td>
<td>0.59±0.13</td>
<td>0.41±0.13</td>
</tr>
<tr>
<td>HIPO1</td>
<td>0.77±0.12</td>
<td>0.23±0.12</td>
</tr>
<tr>
<td>HIPO2</td>
<td>0.54±0.18</td>
<td>0.46±0.18</td>
</tr>
</tbody>
</table>

Table 2 Summary of mean and standard deviation doses (Gy): HR (high risk CTV), IR (intermediate risk CTV).

<table>
<thead>
<tr>
<th></th>
<th>D100HR</th>
<th>D99HR</th>
<th>D90HR</th>
<th>D50HR</th>
<th>D100IR</th>
<th>D99IR</th>
<th>D90IR</th>
<th>D50IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>GrO</td>
<td>3.9±1.0</td>
<td>4.9±1.1</td>
<td>6.8±1.0</td>
<td>10.4±1.4</td>
<td>2.3±0.5</td>
<td>2.9±0.7</td>
<td>4.3±0.9</td>
<td>7.8±1.0</td>
</tr>
<tr>
<td>HIPO1</td>
<td>3.8±1.0</td>
<td>4.9±1.0</td>
<td>6.7±1.0</td>
<td>10.3±1.1</td>
<td>2.3±0.4</td>
<td>2.9±0.6</td>
<td>4.2±0.7</td>
<td>7.6±0.8</td>
</tr>
<tr>
<td>HIPO2</td>
<td>4.1±0.8</td>
<td>5.1±0.9</td>
<td>7.0±0.8</td>
<td>10.5±1.1</td>
<td>2.5±0.5</td>
<td>3.4±1.3</td>
<td>4.6±0.8</td>
<td>8.2±0.8</td>
</tr>
</tbody>
</table>

Summary

HIPO1 reproduces the classic pear-shaped (line A) dose distribution of ring-tandem plans (Figure 1b). HIPO1 significantly reduces large dwell times within the interstitial needles, and hence dose to surrounding normal tissue.

HIPO tends to favour target volume coverage at the expense of OARs, so that some subsequent GrO is generally required. There is some evidence of improved coverage (CTVs) and dose sparing (OARs), observed for both methods (Table 2). HIPO2 tends to achieve better coverage and sparing at the expense of longer needle dwell times. Optimization with HIPO allows treatment planning to be standardized and streamlined, allowing clinically acceptable plans to be generated expediently by inexperienced planners after applicator/catheter reconstruction.
Session 19 I Dosimetry in Particle Therapy and FLASH Irradiation 2

V76  Response homogeneity of large area ionization chambers

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Introduction
The use of large area ionization chambers (LAICs) for scanned particle dosimetry requires detailed information on the uniformity of the response over the sensitive area. The method to determine such response was controversially discussed in recent literature [1-3]. In this study, narrow proton beams were applied to determine the lateral response variation of LAICs from different vendors.

Materials & Methods
A collimated 80 MeV proton beam was used to map the response for four PTW-34080, four PTW-34070, and one PTW-34089. Furthermore, similar measurements were conducted with an IBA StingRay using an uncollimated proton beam (E=256.7 MeV). A collimated 200 kV x-ray beam was used as reference beam quality. Using Monte Carlo (MC) simulations (FLUKA), the secondary electron transport within the chambers was investigated for proton beams.

Results
All PTW34070 and the StingRay showed a response decrease (2–5 %) towards the chambers' edges. Three PTW34080 showed an increase (up to 17%) and one chamber a decrease (8 %). The response of the PTW34089 increased by up to 5 %. Response behavior of all chambers is summarized in Figure 1. The Fano test passed with an accuracy of 0.1 %.

Summary
The investigations showed that the response of LAICs is chamber dependent. Furthermore, the results indicate a similar response for protons and x-rays. The general heterogeneous response of LAICs along the sensitive area needs to be carefully considered in particle dosimetry. Further MC studies will be performed to better understand the variations of the lateral response uniformity of LAICs. In an ongoing investigation the response behavior for carbon ions in comparison to proton and x-ray beams is investigated.
Appendix 1

Figure 1: Radial response of four PTW-34070, four PTW-34080 chambers one PTW-34089, and one IBA-StingRay, normalized to the response in the chambers' center.

References

On the localisation of the proton Bragg peak position in 3D using multilateration of ionoacoustic signals.

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Introduction
When energy is deposited in a medium by a pulsed proton beam, it generates thermoacoustic waves, also called ionoacoustics (IA). Multilateration uses the arrival time estimated from IA signals at different sensor locations to determine the proton beam stopping position. This work investigates different time-of-flight (ToF), e.g., maximum amplitude (MA), zero-crossing, and multilateration methods using experimental and in-silico data.

Materials & Methods
Acoustic range verification was experimentally assessed in a homogenous water phantom at a research accelerator facility using a 20 MeV pulsed proton beam. The IA pressure was measured by 4 single element piezoelectric transducers (1 and 3.5 MHz centre frequency, 0.5 inch diameter). The transducers were chosen according to the expected frequency spectrum at the given position. Range verification was performed employing two different multilateration methods: time difference of arrival (TDOA) and time of arrival (TOA). The accuracy and robustness of the TDOA and TOA were assessed in-silico by modelling systematic uncertainties (e.g., trigger offset), and random uncertainties (ToF error depending on the estimation method and sensor position w.r.t. the Bragg-peak).

Results
According to simulations, the expected proton range in water was 4.17 mm. The relative error of the reconstructed ranges were 0.14\% (TDOA) and 10.21\% (TOA) using ToF-MA. These results refer to single proton shot measurements, each corresponding to a maximum dose of 0.52 Gy at the Bragg-peak. The robustness study revealed that TDOA is more robust against systematic uncertainties, whereas TOA is more robust against random uncertainties. The localization error also depends on the ToF method e.g., it reduces to 3.21\% using TOA combined with zero-crossing.

Conclusion
The accuracy of Bragg-peak localization depends on the multilateration method, ToF estimation and sensor location. Next, we will study the influence of heterogeneities, and design a multilateration system for beam monitoring in a small-animal irradiator.

Supported by ERC.
Experimental determination and Monte Carlo simulation of lateral dose response functions for point detectors in proton beams


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Introduction
Point detector dose measurements in small fields or penumbra regions may be perturbed by the volume effect resulting from extended detector dimensions and charged particle fluence disturbance. According to equation 1 (Looe et al. 2015 PMB 60 6585), detector specific lateral dose response functions $K(x,y)$ can be used to transform the measured signal profile $M(x,y)$ to the dose profile $D(x,y)$.

$$M(x,y) = D(x,y) \ast K(x,y)$$ (1)

The aim of this work is to determine $K(x,y)$ of point detectors in proton beams.

Materials & Methods
Three ionization chambers (PTW Semiflex 3D 31021, PTW PinPoint 3D 31022, IBA Razor CC01-G), a PTW microDiamond 60019, and a PTW microSilicon 60023 were investigated. Experiments with 150 MeV protons were performed at the PARTREC Accelerator Facility (University Medical Center Groningen, University of Groningen). Analogous to the approach for photons (Poppinga et al. 2015 PMB 60 9421), the detectors were scanned across a 0.5 mm wide proton slit beam to obtain $M(x)$ profiles at 2 cm depth in water. The corresponding $D(x)$ was measured with EBT3 films. Using iterative deconvolution, $K(x)$ were derived according to equation 1. Additionally, the setup including detectors was modeled using the Monte Carlo code GATE/Geant4.

Results
The full-width-at-half-maximum of $M(x)$ of all investigated detectors are between 0.6 and 3.2 mm wider than $D(x)$. Figure 1a exemplarily shows the measured and simulated $D(x)$ and $M(x)$ of the Semiflex 3D chamber, which shows pronounced widening from the volume effect. The associated $K(x)$ derived from deconvolution are presented in figure 1b.

Summary
$K(x)$ of five detectors were determined for proton beams, with which strategies can be derived to correct for the volume effect encountered especially in measurements of small and collimated proton beams.
Figure 1: (a) $D(x)$ and Semiflex 3D profiles $M(x)$; (b) $K(x)$ of the Semiflex 3D derived from $M(x)$ and $D(x)$ in (a).
Development of an optical micromegas detector for precision particle beam QA

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Introduction
Small beam diameters of 1mm FWHM and below and low particle energies (20-50MeV), as needed for precision pre-clinical proton irradiation, challenge available quality assurance devices. Radiochromic films yield the desired spatial resolution, but their application is tedious and results are only offline available. We are developing a Micromegas detector with optical readout, able to resolve beam spots below 1mm in real-time and with minimum beam shape distortion.

Materials & Methods
Micromegas detect ionizing radiation through the ionization charge that is produced in a few mm wide, gas-filled region between a planar cathode and a micro mesh. Ionization electrons are amplified in avalanches in 40 kV/cm electric fields between mesh and anode. The scintillation light emitted in the CF4 gas mixture [1] during the amplification is observed through a transparent glass anode with a 1 MPixel EMCCD camera behind a mirror. Detection sensitivity can be tuned for single particle or for beam integrating operation. As the proton beam traverses only a 12µm thick aluminum window and a 2 µm thick aluminized Mylar cathode before registration, beam distortion due to scattering is minimized.

Results
We have developed and successfully tested a prototype with radioactive sources and in 20 MeV proton beams (see Fig. 1). It was possible to detect individual 5.9 keV photons and to record the proton beam shape for various beam currents between 0.03 and 20 pA. An improved version, used to characterize pre-clinical proton beams below 1mm FWHM will be presented.

Summary
Micromegas with optical readout were developed and tested. They are suitable for precise pre-clinical proton beam characterization.

Appendix 1

Figure 1: Shape of a 20MeV, 4mm FWHM proton beam at \(I_{beam} = 12\)pA. The color bar describes intensity in arbitrary units.

References
Feasibility study of correlated Bragg peak localisation via ultrasound and ionoacoustic in an abdominal imaging phantom


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5Centre Antoine-Lacassagne, Nice, France

Introduction
The deposited energy of a pulsed proton beam in a medium converts to heat and provokes thermoacoustic waves [1]. Detecting the so-called ionoacoustic (IA) waves on the patient surface and correlating its signal with an ultrasound (US) image of the traversed medium allows deriving the BP location in such US image. As both modalities rely on acoustic waves propagating through the same tissue [2,3], a relative BP localization on the underlying anatomy should demonstrated for clinically relevant dose levels.

Materials & Methods
This feasibility study is based on an abdominal imaging phantom (CIRS057A) comprised of nine hydrogel materials. CT and MR images were acquired and contouring/image fusion was done using 3DSlicer. Dose calculation is based on an analytical pencil beam algorithm and is currently being replaced by Monte Carlo simulations to reproduce the clinical beam foreseen for future experimental studies (appendix1). IA wave propagation was simulated in-silico and recorded by a hydrophone (Catecean305X). To emulate the clinical experiment upfront, the Catecean305X hydrophone was tested using a pulsed 30 Watt laser pointed onto the phantom to create optoacoustic (OA) waves. The laser intensity was tuned to mimic acoustic emissions produced by clinical proton beams. Co-registration between US and hydrophone was achieved by an in-house developed holder with known spatial offsets.

Results
Based on simulations a relative BP localization is feasible (appendix2). Realistic 30mPa pressure amplitudes were measured with the hydrophone using the OA testbench. Averaging 300 individual measurements was required to identify the OA signal, which translates to a total dose of 2.4Gy at the BP. Post-processing will further reduce the minimum total dose necessary for signal detection.

Summary
Investigations on assessing IA/OA-US correlations in realistic clinical-like anatmies are ongoing and will be presented for in-silico studies and accompanying experiments from the OA testbench. Experiments at a synchrocyclotron facility are planned.
Appendix 1

Figure 1: The dose deposition of 122 MeV protons targeting a lesion within the liver is shown on the left panel. A curved US probe (Interson, GP-C01, 3.5MHz) was positioned distal to the beam. The US image is shown on the right panel with the red arrow pointing to the considered lesion.

Appendix 2

Figure 2: The left panel presents the simulated noiseless pressure amplitude of the IA wave at the position of the US probe. The maximum dose deposition of the Bragg peak is marked by a dashed blue arrow (radius of response) on the left panel. The x-axis is given in millimeter assuming a constant speed of sound identical to the US system. The radius of response corresponds in the 2D US image to an arc of response, which is overlaid in the right panel onto the US image.

Acknowledgement

The authors kindly acknowledge the financial support by the German Research Foundation (DFG), the European Research Council and the European Union Attract initiative.

References

A rapid method for radiochromic film calibration in proton beams exploiting the dose gradient

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2MedAustron Ion Therapy Center, Wiener Neustadt, Austria
3National Physical Laboratory, Teddington, United Kingdom

Introduction
Radiochromic films are versatile 2D dosimeters with high resolution and near tissue equivalence. To assure high precision and accuracy, a rather time-consuming calibration process is required. This study proposes a more (time) efficient method derived from literature [1] to facilitate EBT3 film calibration.

Materials & Methods
The calibration procedure employs the dose ratio of film measurements of the same relative profile, for different absolute doses. Hence, the dose ratio is constant at any point of the profile, and the calibration function is altered until it fulfils this condition. To validate our approach, a treatment plan yielding a radial symmetric proton dose profile was generated, having a centred plateau with a radius of about 1.5 cm and a Gaussian like dose fall-off at larger radii. However, the calculated dose distribution is not used at any further point and the absolute dose enters the proposed optimization as a boundary condition, i.e. the dose measured in the plateau region of the highest dose level. A 179.2 MeV proton beam was used for the experiments and dose measurements were carried out at 2 cm depth in a RW3 phantom (PTW, Germany). The treatment plan resulted in 1 Gy in the central plateau area and the initial number of particles was then linearly scaled by a factor in each of the 12 experiments.

Results
The fitting procedure was found to be stable and calibration functions with dose agreement better than 3 % could be established with as low as two measurement sets, Figure 1. Increasing the number of training data sets resulted in lower dose deviations and less sensitivity on the chosen dose levels.

Summary
The proposed method allows to reduce the required number of calibration measurements considerably while resulting in a dosimetry accuracy similar to our standard calibration protocol. The optimization strategy can be applied to any differentiable function and is in theory independent of the radiation modality.

Appendix 1

Figure 1: Exemplary calibration curve obtained using two measurement sets for training and 10 for the testing.

Radiotherapy is an effective treatment against cancer and proton therapy is one of the most advanced forms of radiotherapy, capable of precisely delivering high doses to the target volume while minimizing dose to surrounding normal tissues. However, proton therapy is particularly sensitive to anatomical changes of the patient during treatment, which can compromise the quality of the plan and can lead to unplanned increases of dose to normal tissues and/or reduced dose to the tumour. The best approach to mitigate these effects is to adapt the therapy on-line in order to directly compensate for the effects of such changes. Despite the growing interest in the proton community however, on-line adaptive proton therapy has not yet been delivered clinically, mainly due to time-consuming and un-streamlined workflows.

The Real Time Adaptive Therapy Of Cancer (RAPTOR) project, recently funded by the European Commission (H2020-MSCA-ITN-2020 n°955956) aims to bring adaptive particle therapy to the clinic. This will open the door to an even more personalized approach to patient treatments with protons, from which nearly all indications currently treated with protons would benefit.

RAPTOR is a network of world-class research institutes and industries hosting 15 PhDs students working on developments required for on-line adaptive proton therapy. The main objectives of the project are 1. to enable on-board volumetric image guidance suitable for on-line (and in the future real-time) adaptive therapy; 2. to streamline the on-line plan optimization and to transition from measurement-based to log-file based QA; 3. to enable imaging of the patient anatomy and/or of the particle during the beam delivery.
**F18** The IDEAL independent dose calculation system for light ion beam therapy

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**Introduction**

Independent Dose Calculation (IDC) was shown to be more sensitive in detecting planning errors than experimental Patient Specific Quality Assurance (PSQA) and can therefore improve the PSQA process by reducing potential accidental exposures [1]. In addition, the implementation of IDC may support light ion beam therapy facilities in reducing the overall PSQA workload.

**Materials & Methods**

The GATE-RTion-based Independent DosE cAlculation system for Light ion beam therapy (IDEAL) was developed for this purpose. It was built in a DICOM-in/DICOM-out fashion, for easy integration into state-of-the-art technology-based workflow for scanned ion beam therapy. After acceptance testing, the commissioning process was conducted, including beam model validation in water and CT calibration validation against experimental data obtained in real pig tissue samples. Finally, 3 clinical carbon ion treatments and 2 proton treatments were evaluated against the TPS (RayStation 8B, RaySearch Laboratories, Stockholm, Sweden) for different treatment locations (para-nasal cavities, abdomen and pelvic regions).

**Results**

Beam sizes were reproduced within 0.3 mm and ranges within 0.2 mm. 3D dosimetric pass-rate at the 5 % dose level for 3D reference boxes was better than 97 % for both protons and carbon ions. Experimental validation of stopping powers using real pig samples were between 1.8 % and 3.8 % for soft tissues. For protons, IDEAL was in rather good agreement with the TPS, featuring also a Monte Carlo algorithm. For carbon ions however, larger differences were observed which could be attributed to limitations of the TPS pencil beam algorithm near air cavities and air/bone interfaces.

**Summary**

The IDEAL system was developed, validated and commissioned in a collaboration between ACMIT, the Medical University of Vienna and MedAustron. It was found to satisfy the clinical requirements for IDC of scanned proton and carbon ion beams.

Session 21 I Free Topics 3
V82 Impact of pulse motion in the brain on the dose distribution of microbeam radiation therapy

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Introduction
Microbeam radiotherapy (MRT) is a novel cancer treatment approach with a spatially fractionated dose of 25-100 µm wide high-dose peaks and a few 100 µm wide low-dose valleys. MRT has superior healthy tissue sparing at equal tumour growth control compared to conventional radiotherapy and was proposed for brain tumour treatments. However, the cardiac cycle induces a pulsatile brain motion with amplitudes of 100-200 µm, which may destroy the micrometre-sized dose patterns. We investigated the motion effect on the MRT dose distribution delivered by a compact source and examined whether gating methods can mitigate this effect.

Methods
We performed Monte Carlo simulations (TOPAS) for a microbeam source in a small-animal irradiator at our institute (XenX, Xstrahl Ltd, 225 kVp). The irradiator was equipped with a multi-slit collimator with 50 µm slits and 400 µm pitch, 212 mm away from the source. A PMMA phantom was placed directly behind the collimator and moved 200 µm forwards and backwards along the peak-valley-profile with a speed of 1 µm/ms, representing the worst-case scenario of brain motion in small animal experiments. Furthermore, gating with a 50 % gating window was implemented.

Results
Pulse motion induced a reduction in the peak-to-valley dose ratio (PVDR) and an increase of the peaks’ full width at half maximum (FWHM) compared to static phantoms. On the surface of the moving phantom, the PVDR was 14 (47 without motion) and FWHM 196 µm (47 µm), see figures 1 and 2. A 50 % gating window improved PVDR (28 at the surface) and FWHM (95 µm). The results were also obtained by convolving the static dose profile with the probability density function of the phantom position.

Summary
Cardiovascular brain motion impairs the microbeam dose distribution of a compact X-ray source by decreasing PVDR and increasing FWHM. Cardiac gating can mitigate the motion effect.
Figure 1: Peak-to-valley dose ratio (PVDR) in a moving, static and gated phantom.

Figure 2: FWHM for a moving, static and gated phantom.
Acceptance tests and characterisation of a plastic material with a 3D printer for the production of personalised 3D-printed immobilisation shells for prone breast radiotherapy

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Introduction
We report on the characterization of the combination of our selected 3D printer with a special acrylonitrile butadiene styrene (ABS) material and we assess skin doses (SkD) for 3D-printed shells.

Materials & Methods
The ABS material was tested with 4 printers of the same model. Tapered cylinders (32.5-29.5x82 mm\textsuperscript{3}) for CIRS062 phantom, flat slabs and curvilinear objects were 3D-printed, to test density reproducibility, response to CT, radiation absorption (PDD) with film dosimetry [1], time stability of Hounsfield Units (HU), and dimensional accuracy. Dimensions were measured using a caliper and a surface scanner. To measure SkD, TLDs were positioned on a breast phantom under 3D-printed slabs: 5mm thick (entire, 100% infill) and 3mm thick (entire with 25% and 50% infill and 2 different perforated slabs). For reference, SkD was also measured with no slab and under a 5mm Superflab slab. A 6MV beam was used with CBCT for phantom alignment and TLD visualization [2]. The SkD increase factor (SkDf) is defined as \(((\text{SkD}_{\text{under_slab}}/\text{SkD}_{\text{without_slab}})-1)*100\). Measured SkD was compared to the TPS calculation for the 5mm slabs [3].

Results
Table 1 gives the results for the cylinder measurements. After 7 months, the mean HU had increased by 5 HU. Measured PDDs were within 2% of the TPS calculation. ABS CT-calibration curve, Figure 1, matched literature data [4]. Cylinder dimensions were excellent, Table 1. Surface scans of large (350x330x120 mm\textsuperscript{3}) and small 3D-prints showed maximum differences with the model of the order of 0.7mm and 0.2mm, respectively. SkD under the 5mm ABS or Superflab slab was within 6% of the TPS calculated dose. Mean (±SD) SkDf varied between (117±19)% and (27±7)%.

Summary
We have shown that the 3D printer with the special ABS material has the potential to produce 3D-printed immobilization devices with SkDf smaller or similar to thermoplastic masks [5,6].

Appendix 1

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{This figure shows how our standard calibration curves models ABS 3D-printed material properties. The CT calibration curve used at our institution is presented in black.}
\end{figure}
Table 2: Several measured data are reported in this table: dimensions of the tapered cylinders as measured using a caliper, weight measured using a precision scale and mean Hounsfield Units (HU) with its respective standard deviation (SD) as measured on CT data. Abbrs.: ID= identification; diam.= diameter; Delta-vol. = Tapered cylinder reference volume (61.94cc) minus measured volume.

References


**V84** Commissioning of 3D-printed bolus fabrication for external beam therapy

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**Introduction**
For the treatment of superficial lesions on a linear accelerator, a bolus for dose build up is essential. With complex anatomy, 3D-printing provides a quick and accurate way of production. The process consists of CT images of a patient, Eclipse (Varian Medical Systems, USA) for bolus design, 3D Bolus (Adaptiiv, CA) and Repetier-Host software (Hot-World GmbH, GER) for conversion to printer instructions and an AXIOM20 3D-printer (Airwolf3D, USA) for printing. Radiation attenuation properties of the printed material have to be defined in the treatment planning system and the entire process verified by measurement.

**Materials & Methods**
We use polylactic acid (PLA) as material for 3D-printing. The relative electron density (relative to water) of PLA derived from its chemical composition is ~1.14. In Eclipse a HU value of 260 was used. For verification of the HU value, slabs with thicknesses from 5 – 25mm were printed. With these slabs, percent depth-dose (PDD) for a 6MV photon beam were measured in a water phantom and compared to calculated PDD from Eclipse. For quality assurance (QA) of the printed bolus, size and weight measurements were used. The bolus fit to a surface was verified with a CT or CBCT. For in-vivo dose verification, thermoluminescent dosimeter (TLD) were used.

**Results**
PDD from slab phantom measurements agreed with the calculated PDD with a gamma criterion of 2mm/2 % with over 90 % points passing. The printed parts met QA tolerances within the limits of ± 1 mm in height and ± 5% of the estimated weight. TLD measurements with an CRIS ATOM-phantom (CIRS, USA) agreed within 5 % to the calculated dose.

**Summary**
3D-printed bolus provides an efficient way of producing patient-specific bolus even with challenging surface anatomy. The printer is reliable and dose calculation is accurate. Printed bolus were used for two patients with no issue.
V85  Production of photon blocks and electron apertures for TBI treatment using a 3D printer

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Introduction
Due to the increasing application of intensity modulating techniques there is nearly no need for the production of photon blocks. However, for special applications they are still useful. Lung shields to avoid pneumonitis after total body irradiation (TBI) are rather common. We demonstrate the production of photon blocks and electron apertures for TBI using a commercial 3D printer.

Materials & Methods
The configuration of the blocks is performed using the treatment planning system Oncentra [1]. The RT plan DICOM file is exported to an in-house developed Matlab® program. This generates a 3D-model of the blocks under consideration of geometric parameters. The molds for electron aperture cut-outs are calculated as complementary shapes of the photon blocks. The surface file from the Matlab program is imported in the PrusaSlicer software which creates a gcode file for the printer type Prusa i3MK3S. We chose standard printing materials as PLA and PETG. The moulds were filled with MCP96.

Results
The geometric shape of the molds for blocks and apertures corresponds precisely to the requirements. Both materials PLA and PETG showed sufficient heat resistance when filled with molten MCP96 without visible deformation. The required height of photon blocks is achieved by printing the mold in the specified height.

Discussion and Conclusion
The material of the actual medical product – the blocks and apertures – is unchanged compared to the former production process with polystyrene foam (PS) cutting devices. The blocks can be handled in the accustomed manner. However, the 3D printing process takes more time than cutting a mold of PS foam. This must be considered in the treatment preparation.

References
Metallic scanning structure of a 3D water phantom affects measurements in medium energy kilovoltage beams

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Introduction
We investigated the dosimetric influence of the metallic scanning arm (MSA) of a 3D scanning water phantom on the measured signal in the medium energy kilovoltage range. Water phantoms are primarily designed for the use in megavoltage beams. Due to increased backscatter in water and increased photoelectric absorption in metal for kilovoltage photons, the proximity of a detector close to the MSA has the potential to significantly decrease its signal.

Materials & Methods
Dose measurements under reference conditions were conducted on a BEAMSCAN phantom (PTW). Two different holders were used to mount the detector on the MSA: the standard holder and a generic holder with chamber-to-MSA distances of 35mm and 115mm, respectively. The dose reduction due to the use of the standard holder was determined. Measurements with the generic holder served as undisturbed reference values.

Additionally, relative depth dose curves and dose profiles were measured. Measurements were done on a WOmed T-200-kV unit for 5 different applicators (4x6 cm² to 15x20 cm²) and 7 energy/filter combinations (75kV/1mmAl [1.HVL=1.74mmAl] to 200kV/1mmCu [1.HVL=1.50mmCu]).

Results
For the largest applicator, the dose reduction ranged from (1.2 ± 0.3)% to (2.95 ± 0.08) %, (k=2). The minimum effect was found for 75 kV/1mmAl and the maximum effect for 150kV/0.5mmCu. Dose reduction for applicators with field sizes smaller or equal 6x8 cm² was less than 1 %.

The symmetry of dose profiles measured parallel to the MSA was degraded by up to 3 %. Relative depth dose curves and dose profiles orthogonal to the MSA were not significantly affected.

Summary
Contrary to the experience with MV beams, the influence of the mounting structure cannot be ignored in the kV energy range.
The standard holders position detectors in immediate vicinity of the MSA and measured doses are significantly reduced.
Using alternative holders with increased detector-to-MSA distance eliminates the dosimetric influence of the MSA.
Calibration of TLD 100H on CT with a 3D phantom

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Introduction
For absolute dosimetric measurements with thermoluminescent dosimeters (TLDs), the TLDs must be calibrated to the radiation quality to be used. In dual-energy CT, the radiation quality for CT cannot be easily simulated with conventional X-ray tubes and using 2D calibration phantoms.

Materials & Methods
A two-part cylindrical phantom was developed to irradiate and thus calibrate the TLDs directly on the CT with arbitrary radiation quality and the CTDI measuring chamber usually available (figures 1 and 2). For a dual energy CT protocol, only a collimation of 40 mm was possible. Due to the active length of the CTDI chamber of 100 mm, a homogeneous field had to be generated within its measuring range and the positioning of the TLDs. This was achieved by multiple overlaps of the scan area with a feed rate of 5 mm per irradiation (see figure 3). The homogeneity was tested with a Gafchromic® EBT2 film.

Results
There are no discernible deviations resulting from a positioning inaccuracy of the 3D phantom compared to the conventional 2D phantom. The mean difference between the two relative responses was 4.8 %. The film showed that a homogeneous field could be generated by shifting the individual scans (figure 3).

Summary
The 3D phantom presented here for calibrating TLDs directly on the CT can be used to determine the calibration factors of the individual TLDs with the radiation quality to be examined.

Appendix 1

Figure 9: 3D phantom for determining the calibration factors of 50 TLDs directly on the CT
Figure 10: Axial view through the 3D phantom: 50 circularly arranged bores for receiving the TLDs and the CTDI chamber (above)

Figure 11: Dose progress by superimposing several scans
Sound localisation in bimodal listeners using a hearing aid and contralateral a cochlear implant

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Introduction
In few cases of sensory-neural hearing disorders the associated hearing loss is asymmetric. If the degree of hearing loss is moderate on one side and profound on the other side these patients are bimodally supplied with a hearing aid (HA) and contralateral with a cochlear implant (CI). Aided hearing thresholds and speech reception scores are often considerably improved in the bimodal situation. However, binaural hearing abilities are still limited. The reason may be the differences in signal transfer via hearing aid in comparison to electrical stimulation of the auditory nerve through the cochlear implant. In particular, electrical stimulation with CI may be ahead of time to acoustic stimulation with HA. In the present study sound localization in bimodal listeners is studied with focus on the aspect of stimulation timing.

Methods
In total 10 listeners with bimodal supply of HA and CI were included in the study. Sound localization tests were performed in an anechoic chamber using an array of seven loudspeakers in front of the test persons. A system of two audio-processors enabled for delaying the CI signal in order to synchronize signal transfer of the HA and the CI. As a starting value of the CI signal delay the processing time of the hearing aid was set. In all patients sound localization tests were performed in the “daily use” condition, where no delay was applied, as reference.

Results
The angular error of this study group amounted to 40° in the “daily use” condition. When delaying the CI signal the angular error was significantly lower, i.e. 32 – 36°, in all tested delay conditions compared to the “daily use” condition.

Summary
Synchronization of CI and HA may be possible to a certain extend and may contribute to further optimization of sound localization abilities of bimodal listeners.


In dem Vortrag werden die unterschiedlichen Aspekte der Messung des Richtungshörens im freien Schallfeld mit den gegenwärtig verfügbaren Messanlagen bei wichtigsten, im Zusammenhang mit dem beidohrigen Hören stehenden, klinischen Fragestellungen vorgestellt.
Reference Data for Sound Localization in the Horizontal Plane

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Introduction
Sound localization describes the correct spatial allocation of a sound source and requires binaural hearing. In clinical routine, it is important in the diagnostic of asymmetric hearing loss and the treatment with hearing aids that usually follows. This is due to the fact that measuring the sound localization can prove a benefit of binaural hearing. The aim of this study was to collect reference data of sound localization in the horizontal plane and to analyze the test-retest-reliability.

Methods
Twenty-five normal-hearing subjects, aged between 18 and 25 years, participated in this study. Sound localization was measured in a semicircle setup comprised of 7 loudspeakers and in a full circle of 12 loudspeakers. Sentences from the Göttinger sentence test were used as stimuli and presented to the subjects, with an average sound level of 65 dB, combined with a level stroke of 5 dB. Semicircle and full circle measurements were arranged randomly. In order to determine the test-retest-reliability, the measurements were conducted twice. Root mean square (RMS) was used to quantify the deviation of sensational direction and signal direction.

Results
For the first full circle measurement a mean RMS of $12.70°±10.80°$ was observed, respectively $7.50°±4.40°$ for the second measurement. Using the semicircle setup, a mean RMS of $2.80°±4.10°$ was measured in the first measurement as well as $0.90°±2.10°$ in the second measurement. In both loudspeaker arrangements the retest was significantly better than the initial test ($p<0.01$). The test-retest-reliability was $19°$ for the full circle and $6°$ for the semicircle.

Conclusion
Reference data and test-retest-reliabilities for sound localization in the horizontal plane were successfully obtained. Thereby, we found a learning effect in both the full circle and semicircle setup. This effect was possibly due to three data outliers and may be reduced with improved patient information or training.

Literature
Models of test-retest statistics of directional hearing in the full horizontal plane

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Introduction
Directional hearing is necessary in daily life, but a challenging task for hearing-impaired patients, especially for cochlear implant (CI) recipients. In our clinical routine, the progress of their development is evaluated in a localization experiment in the full horizontal plane. Since the routine is time-consuming, two approaches to model the test-retest statistics basing on Gaussian and on surrogate data were investigated with different directional hearing measures suggested by different authors.

Materials & Methods
The localization experiment consists of a circle of 12 loudspeakers, placed in an anechoic room, a “camera silens”. In darkness, HSM sentences are presented from all directions with five repetitions at 65 dB pseudo-erratically. Four directional hearing measures were used exemplary to compare the two approaches modelling the test-retest statistics. The Gaussian model bases on the hypothesis that Gaussian distributions with different standard deviations are added to a perfect estimator. The surrogate data approach uses the five repetitions per direction to simulate data distributions for the sensation directions.
We retrospectively use the data of 33 CI patients with 92 pairs of test-retest-measurements from the same day to compare the test-retest statistics.

Results
The introduced models describe test-retest statistics of directional hearing, but perform differently. Although inversion of direction - these are permutations of the direction from back to front and vice versa - are common for hearing impaired recipients particularly in the rear hemisphere, the Gaussian model is unable to model them. The surrogate data model considers these inversions but does not work with a highly non-linear measure.

Summary
Two approaches were suggested to model test-retest statistics of directional hearing. They still have to be tested on a larger data set. If applicable, they can reduce measurement time avoiding retests and enable pair test comparisons for localization experiments.

Reference
Development of fluence modulated proton computed tomography

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Fluence modulated proton computed tomography (FMpCT) aims at obtaining both high relative proton stopping power (RSP) fidelity in terms of accuracy and precision, and minimal dose from image guidance. This is achievable by acquiring FMpCT scans using the pencil beam scanning (PBS) capabilities found at modern proton therapy facilities and would allow daily image guidance and potentially low-margin plan adaptation. This contribution will highlight the experimental and optimization steps required to obtain patient specific, deliverable projection-per-projection fluence patterns. The basic effects contributing to noise in pCT will be revised. Focus will be on implementation for the phase II pCT scanner of the US collaboration currently operated at the Northwestern Medicine Chicago Proton Center and will demonstrate the feasibility of obtaining dose- and image-quality- optimal FMpCT plans.
Current and future particle imaging activities at MedAustron

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Introduction
Ion beam therapy has become an established method for treating deep-seated tumours. For treatment planning precise information on the stopping power in a patient is required. Currently this information is obtained by extrapolating from Hounsfield units, determined by x-ray computed tomography, to relative stopping powers (RSP). By using ion computed tomography (iCT), the RSP distribution can be measured directly, potentially leading to superior accuracy in the treatment planning process.

Materials & Methods
An iCT demonstrator, consisting of double-sided silicon strip detectors for tracking and plastic scintillator slabs coupled to silicon photomultipliers as a range telescope was developed [1] and tested at the MedAustron facility in Wiener Neustadt, Austria. For image reconstruction, the GPU-based open-source software toolkit TIGRE was used [2]. A feasibility study for an upgraded system using position sensitive time-of-flight (TOF) detectors for particle tracking and residual energy detection was performed using Geant4 simulations.

Results
Results obtained from images reconstructed using data measured with the current iCT demonstrator at MedAustron will be shown and discussed. First results from the feasibility study for a TOF-iCT system will be presented.

Summary
Our demonstrator was successfully tested in a proton beam and first tomographic data could be acquired and reconstructed. Furthermore, we established an upgrade path using an innovative concept, which could pave the way for new solutions for the development of a future clinical system.

References
F21 Proton imaging for small animals

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Introduction
Precision small animal proton irradiators are emerging technologies. For in-situ image guidance they typically foresee integration of X-ray cone-beam CT cabinets established in small animal photon irradiators. However, for treatment planning, such imaging solutions cannot guarantee accurate prediction of the proton beam stopping within the small animal.

Materials & Methods
We are investigating different solutions of pre-treatment proton radiography and tomography for integration in an innovative system under development for precision small animal proton irradiation [1]. Compared to clinical applications, the low energies required to image small animals pose challenges, particularly enhanced scattering and more pronounced energy dependence of the stopping power ratio (SPR). Our most advanced solution under development in-house for single particle tracking with residual range measurement relies on micro-pattern gas detector technology of minimal material budget. Moreover, two alternatives using pixelated Si-based detectors providing spatially resolved detection of individual or integral proton energy deposition are being evaluated for operation at facilities of elevated instantaneous beam current (e.g., synchrocyclotrons) to overcome count rate issues, besides offering compact setup.

Results
First experimental results from pixelated silicon detectors for an imaged phantom with tissue equivalent inserts showed promising sub-millimeter spatial resolution with SPR retrieval accuracy better than 3 %. Moreover, the simulated performance of the proposed single particle tracking system for a realistic mouse anatomy showed average range errors below 1 %, when using the resulting proton computed tomography image (acquired with a dose < 100 mGy) for planning.

Summary
This presentation will highlight different imaging concepts and their ongoing development, including updates from upcoming experimental campaigns.

Acknowledgement
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References
Investigation of the effect of air gap size on the spatial resolution in proton- and helium radio- and tomography

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Introduction
Proton computed (transmission) tomography (pCT) refers to the process of imaging an object by letting protons pass through it, while measuring their energy after, and their position and (optionally) direction both before and after their traversal through that object. The so far experimental technique has potential to improve treatment planning of proton therapy by enabling the direct acquisition of a proton stopping power map of tissue, thus removing the need to obtain it by converting X-ray CT attenuation data and thereby eliminating uncertainties which arise in the mentioned conversion process. The image reconstruction in pCT requires accurate estimates of the proton trajectories. In experimental pCT detector setups where the direction of the protons is not measured, the air gap between the detector planes and the imaged object worsens the spatial resolution of the image obtained. In this work we determined the mean proton paths and the corresponding spatial uncertainty, taking into account the presence of the air gap.

Materials & Methods
We used Monte Carlo simulations of radiation transport to systematically investigate the effect of the air gap size between detector and patient on the spatial resolution of proton (ion) computed tomography for protons with an energy of 200MeV and 250MeV as well as for helium ions (He-4) with an energy of 798MeV. For the simulations we used TOPAS which itself is based on Geant4.

Results
For all particles, which are detected at the same entrance and exit coordinate, the average ion path and the corresponding standard deviation was computed. From this information, the dependence of the spatial resolution on the air gap size and the angular confusion of the particle beam was inferred.

Summary
The presence of the airgap does not pose a problem for perfect fan beams. In realistic scenarios, where the initial angular confusion is around 5mrad and for typical air gap sizes up to 10cm, using an energy of 200MeV a spatial resolution of about 1.6mm can be achieved. Using protons with E=250MeV a spatial resolution of about 1.1mm and using helium ions (He-4) with E=798MeV even a spatial resolution below 0.7mm respectively is attainable.
Introduction
MR-integrated particle therapy has been thoroughly described as being a significant improvement to the efficacy of particle therapy[1,2]. It is currently being developed or studied by various groups around the world and progress is at different stages[3,4,5]. In this presentation the key knowledge gaps and technical challenges will be described and discussed.

Materials & Methods
A general summary of the progress so far will be be presented, with focus on the successes and concerns raised. Approaches to achieving the various solutions for the challenges will be discussed.

Results
Despite the broad progress towards MR-integrated particle therapy, it is clear that several elements will require special attention to fully realize the potential of the new modality. These include magnetic decoupling of the beam delivery system from the MRI scanner and robust end-to-end treatment planning workflow. Some elements of dosimetry still require further examination.

Summary
In this presentation an overview of the knowledge gaps and technical challenges is provided. Based on the positive results thus far, development of this modality is progressing at a fast rate. It is likely that the first clinical treatments may be delivered within the next 2 years.

References
Introduction
MRI-guided proton therapy requires the capability of planning and delivering high conformal dose distributions in the presence of the MRI magnetic field. The proton beam transport through the MR fringe field can cause significant deflection which needs correction [1]. We present an in silico study of IMPT treatment planning feasibility for MRI-integrated proton therapy.

Materials & Methods
We considered a realistic 1T split bore MRI system [2] integrated with a proton pencil beam scanning gantry in parallel and perpendicular orientations. The proton beam transport is simulated with Monte Carlo using TOPAS [3]. The research TPS matRad [4] was extended for IMPT planning in presence of MR magnetic field. The beam deflection is accounted for in the selection of the pencil beam energy and scanning angles. IMPT plans in the presence of the MR magnetic field are compared to reference plans calculated in absence of the MRI for different treatment sites.

Results
The beam delivered in the parallel orientation is characterized by a rotation around the beam axis. A software-base adaptation of the beam spots can compensate for this rotation. Conversely, a lateral beam deflection in the perpendicular orientation is too large to allow for the delivery of plans without hardware changes. In this case, a gantry angle offset and a PBS nozzle skew allow to achieve equivalent irradiation as in the reference conditions. All metrics for the adapted planning in the MR magnetic fields are equivalent to reference plans.

Summary
Robust methods to account for the proton beam deflection during IMPT treatment planning in MRI-integrated proton therapy have been successfully presented.

References
Joint Conference of the ÖGMP, DGMP and SGSMP

F25 Proton beam visualisation for in-beam MR imaging

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Introduction
In-beam MRI is expected to improve the targeting accuracy of proton therapy for moving target volumes providing real-time anatomical images and allowing the simultaneous visualisation of the therapeutic proton beam in liquid-filled phantoms [1,2]. The aim of this contribution is to provide an overview of our previous work on MRI-based proton beam visualisation.

Materials & Methods
A 0.22 T open MR scanner was positioned at a fixed horizontal proton research beamline in a clinical proton therapy facility. Water, ethanol, petroleum and mayonnaise phantoms were irradiated with nominal proton beam energies between 190 - 225 MeV at beam currents of 1 - 64 nA. A range of pulse sequences was used for the acquisition of a horizontal slice within the beam volume. Material, sequence, beam current and energy dependence of the beam signal were evaluated.

Results
The proton beam induces a beam current and energy dependent MRI signal in liquids of low viscosity. For fixed beam current setting, the beam range in water extracted from the MR images matches the expected residual range within a few millimetres. Gradient echo-based pulse sequences appear more sensitive to the beam-induced effect than spin echo-based sequences.

Summary
The method holds potential for on-line quality assurance for MR-integrated proton therapy. The underlying image contrast mechanism requires elucidation to enable the development of specifically tailored sequences with increased sensitivity for the beam-induced effect.

Appendix 1

Figure 1: Beam current dependence of the 207 MeV beam signal in water acquired using a Time-of-Flight-Angiography sequence.
Figure 2: Inversion Recovery-Gradient Echo images of water under irradiation at a beam current of 9 nA. The dotted lines indicate the expected proton ranges.

References
Session 24 I Radiation Protection, Quality Assurance and Risk Management in Radiology and Nuclear Medicine 2

V92  Tc-99: Are there consequences from the new radiation protection regulations?

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Introduction
Radionuclide impurities have recently shifted to the center of attention. Due to the new German radiation protection regulations (attachment 4, Tab. 1 StrlSchV 2018), the maximum permissible value (MPV) of Tc-99 in non-radioactive waste was modified. Caused by removal of the special prescription for small amounts of waste (< 100 t), the exemption limit for unlimited use of Tc-99 decreased from 6 to 1 Bq/g. As Tc-99 accrues permanently as daughter nuclide of Tc-99m generated from Mo-99 decay in nuclear medicine departments, consequences for the management of radioactive waste have to be investigated.

Materials & Methods
As an example, Tc-99 accruement of a typical Mo-99/Tc-99m generator (12 GBq) is calculated and related to the MPV. The Mo-99 transport activity of the examined generator is 35 GBq. Considered half-lifes (HL) are 65.9 h for Mo-99 and 2.1 E+05 a for Tc-99. From the relation of the HLs (Mo-99/Tc-99) of 3.6E-08 the overall Tc-99 generation can be calculated.

Results
All in all the generator produces an activity of 1.23 kBq Tc-99. Half of the Tc-99 activity is generated during transport and extracted with the first elution. However, there may be some Tc-99 accumulated in the chromatographic matrix even before transport. Tc-99 content of the eluate of the following days corresponds to 22 % of the remaining activity on each day. Therefore, Tc-99 will accumulate in the radioactive waste, depending on the Tc-99m activity not administered to the patients.

Summary
The fraction of Tc-99 in the radioactive waste should be proven carefully and conservatively to avoid conflicts with the new radiation protection regulations. If necessary, consequences have to be drawn concerning waste production or procedure of disposal (e. g. waste combustion).
V93 Evaluation of x-ray tissue-equivalence of 3D-printing materials

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Introduction
3D-printing technologies are increasingly used for the development of individual, anthropomorphic phantoms for dosimetry and radiation protection issues. Fundamental for this is the use of tissue-equivalent materials. To this end, attenuation and absorption properties of printing-materials in the diagnostic energy range were evaluated in this study.

Materials & Methods
Twenty commercially available fused-deposition-modelling filaments were evaluated regarding their tissue-equivalence for several x-ray radiation qualities (70-140 kV, 7 mm Be, 2.5 mm Al) using a two-step approach: (i) measurements of depth dose profiles in and the transmission of x-ray radiation through printed absorbers and (ii) geant4 Monte-Carlo-simulations to obtain comparable values for reference tissues.

Measurements were performed for two different beam setups using a stem chamber (PTW, M23331) and thermoluminescent dosimeters (TLD-100). Both setups were simulated in geant4 using similar x-ray spectra, as verified for conventional PMMA.

Experiments and simulations were compared by using the relative difference between measured and simulated dose values, rD.

Results
The rD values for PMMA were found to be below +/- 3%. Considering inherent uncertainties, the acceptance level for tissue-equivalence of materials was set to rD < +/- 5%. Appropriate filament materials fulfilling this requirement for the investigated radiation qualities were found for muscle, lung, adipose and dense breast tissues. Cancellous bone could be mimicked, however a systematic energy dependence of rD was observed. Due to large deviations in the transmission analysis, no suitable material was found for cortical bone. In this case, however, rDs of absorption data were lower and less energy dependent as the transmission data.

Summary
By using the presented two-step approach, it could be shown that various 3D-printing materials have attenuation and absorption properties similar to that of soft-tissues and cancellous bone and can thus be used to produce application-adapted phantoms for dosimetry and quality assurance.
Hunters of the lost apron - The annual check of X-ray protective devices and its problems

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Introduction
The annual check of the level of protection of wearable X-ray protective devices is mandatory and usually a requirement given in the operational approval. The relevant Austrian Standard gives hints on how to carry out these inspections. Our hospital tries to establish a process, which guarantees these inspections in the whole hospital instead of certain clinics only. The radiology medical physicists investigated the experiences of other institutions concerning systematic checks of X-ray protective devices.

Materials & Methods
We conducted a survey by mail, phone and social media. We contacted medical physicists in different institutions and clinics, as well as in institutions responsible for the implementation of radiation protection. We collected the answers and compared them with the procedures in our department.

Results
Except for one hospital in Vienna there seems to be no hospital in Austria, where uniform procedures for the whole institution exist for the inspection of X-ray protective devices. Instead, everything is organised on departmental level only. Almost in every department/institution, radiographers do the annual checks of these protective devices. In rare cases technicians carry out these inspections or medical physicists coordinate the processes. Most clinics put identification tags/numbers on them and try to keep the overview by self-designed Excel-sheets. Usually pictures of inspected protective devices are stored only when failures in the level of the protection are detected. Many of the responsible persons for the execution of the inspections reported difficulties in organising the measurements.

Summary
This first national comparison of the procedures in the quality control of X-ray protective devices found some echoes in the communities, as well as in the industry in this field. Certainly in the future, this topic will gain more prominence. Then the results of our survey might come in handy.
A method to avoid line artefacts on x-ray images of patients with an implanted Ventricular Assist Device

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Introduction

At our clinic, patients with a Ventricular Assist Device (VAD) are imaged regularly, either daily (while in intensive care) with a mobile x-ray unit or monthly (in ambulatory care) with a stationary direct-radiography system. In both cases, line artefacts have been observed, sometimes rendering an image unreadable for the radiologist.

Materials & Methods

From retrospective evaluation of artificial heart patient images in our PACS it has been determined that the artefacts are not dependent on patient size, make/model of x-ray unit or imaging parameters. Therefore, two VADs, HVAD (Heartware VAD) and HM3 (Thoratec Heartmate 3), used in our clinic were imaged with two different mobile units (FujiFilm FDR Nano, Shimadzu MobileDaRT). The two VAD systems differ in their operation: the HVAD has a mini centrifugal pump with hydromagnetic levitation of the rotor, whereas the HM3 uses a magnetically levitated turbine pump.

To mimic absorption in the patient body, an image quality phantom (Quart and/or PTW) with 30 mm PMMA was placed between the detector and the VAD. In addition, a 25 mm Al absorber was placed close to focus to simulate the patient. To remove the line artefacts, shielding the detector with a mu-metal foil fitted into a mobile grid holder was tested.

Results

The artefacts are due to the magnetic field present in a VAD affecting the flatpanel detector. Due to its well-known shielding properties, the mu-metal shielding removes artefacts everywhere except “inside” the heart pump on images with the QA phantom.

Summary

Mu-metal shielding has been shown to work for phantom images. A device conforming to law (Medicinal Devices Act) has to be obtained and tested under clinical conditions.

Appendix 1

Figure 1: Photo (left) and x-ray image (right) of VAD HM3 on top of image quality phantom, the x-ray image showing artefacts
Impact of contrast and respiration conditions on the calculation of water equivalent diameter

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Introduction
The introduction of size-specific metrics in CT, has allowed for more personalized dosimetry. The main metric for Size-specific dose estimates (SSDE), namely the water equivalent diameter (WED), is calculated from the HU-values, which can be affected by several parameters. This study investigates the impact on the WED of contrast in CT abdomen and respiration process in CT chest.

Materials & Methods
All data were acquired using the dose management system installed at the hospital (DOSE, Qaelum, Belgium).

A. In 251 CT triple-phase abdomen examinations (no-contrast/arterial/venal phase), the influence of contrast on WED was investigated. Repeated-measures ANOVA with Tukey's Multiple Comparison was used to find significant differences (p<0.05) between the WED of the three phases.

B. A set of 1148 chest CTs with an inspiration and expiration acquisition was used to evaluate how the respiration process affects the WED. The WEDs of the two acquisitions were compared (paired t-test, significance level 0.05).

Results

A. The WED between the two contrast phases (arterial-venal) of the abdominal scans was not significantly different (p>0.05). The WED of the no-contrast phase was statistically significantly different (p<0.05) from the two contrast phases. However, the difference was <1cm in more than 89 % of the cases.

B. The WEDs of the inspiration and expiration acquisitions were statistically different (p<0.05). The difference ranged from -3.6 cm to 4.5 cm and 63 % of the cases had a difference <1 cm. This led to a median difference in SSDE conversion factors of 3 % (range:-14 %,+16 %).

Summary
Contrast in abdomen exams influences the WED, however in most cases the effect is not clinically relevant. The breathing conditions during a chest CT though, seem to have a significant influence on the WED and therefore SSDE. It might be relevant to report the acquisition protocol, and thus the breathing condition, when a WED is reported.
Ultrasound guided Biopsy Needle Detection based on Single-Board Computers

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Introduction

Automatic detection of biopsy needles in ultrasound b-mode images during interventions ensures precise needle insertion and avoids injuries in surrounding healthy tissue. This study presents real-time imaging and image processing using single-board computers which are inexpensive to purchase and operate, space-saving due to their small size and easy to transport.

Materials & Methods

A needle guidance system with integrated ultrasound-probe holder is constructed for easy and accurate handling of all devices (Figure 1). The recorded ultrasound images are transferred from the sonography device (GE, LOGIQ C5 Premium) to the computer. During image pre-processing, the developed python software\textsuperscript{1} uses angle-dependent Sobel and Gaussian filters to increase the needle visibility (Figure 2). For each line in a pre-defined line coounter the cumulated sum of the filtered frame’s pixel intensities is calculated to determine the needle’s axis. The needle tip is detected via a sliding window approach. The minimum differential of average pixel intensities from two adjacent windows indicates the needle’s tip. [1]

Results

The developed experimental setup and software allow the detection of biopsy needles as long as there are no strong artifacts near the needle in the image. Processing an image on a single-board computer takes at least 0.15 seconds corresponding to five images per second when the whole process is considered.

Summary

The goal of developing a real-time application is achieved. Further validation of the accuracy as well as improvement of the needle holder and runtime of the program are planned.

References


Figure 1: Image of the constructed needle guidance system including the ultrasound-probe holder.
Figure 2: Procedure of needle and tip detection using an ultrasound image from the biopsy of an agar phantom.

1https://github.com/janwolzenburg/us-detection-biopsy-needle
Investigation of the RUBY head phantom and MultiMet insert for multiple-targets end-to-end testing

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Introduction
The RUBY head phantom in combination with the System QA insert MultiMet (PTW Freiburg, Germany) offers the possibility for the simultaneous dose measurements at the isocenter and two off-axis positions. In this study, the system was implemented for end-to-end testings of various single-isocenter multiple-targets stereotactic treatment plans.

Materials & Methods
A planning CT of the head phantom positioned in a stereotactic mask on the stereotactic treatment board was performed. Single-isocenter multiple-metastases VMAT plans were created using the Oncentra Masterplan treatment planning system (TPS) (Elekta, Stockholm, Sweden) with the collapsed cone algorithm. Coplanar and non-coplanar plans using table rotations of 0°, 315°, 45° and 270° were optimized for three spherical target volumes of 0.5 cm, 1 cm, 2 cm, 3 cm and 4 cm in diameter each centered around the three measurement positions. All plans were recalculated with a Monte Carlo algorithm in the Monaco TPS (Elekta, Stockholm, Sweden). Measurements were performed at an ELEKTA Synergy linear accelerator (Elekta, Stockholm, Sweden). After the phantom was positioned with a cone-beam CT, point measurements at all three target positions were performed simultaneously with three PinPoint 3D chambers (type 31022, PTW Freiburg, Germany). The measurement values were compared to those calculated by both TPS.

Results
Measurements and TPS data were shown to be in good agreement. For small target volumes the measured dose was lower due to the chamber volume effect but agree mostly within 5% to the TPS calculations. The non-coplanar plans with 315° table rotation showed higher deviations of up to 13% from the TPS data in one off-axis target position. Further evaluations revealed that this could be attributed to the calibration of the isocentric table rotations.

Summary
The RUBY head phantom in combination with the System QA insert MultiMet was shown to be suitable for end-to-end testings of multi-metastases treatments.
eP37 Development of a multi-modality end-to-end-test phantom with the possibility to determine the compound isocenter

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Introduction
Quality control (QC) in radiation therapy plays a crucial role in ensuring a precise patient treatment. To perform this QC at the linear accelerator, the imaging devices and the treatment planning system an appropriate phantom is required. In this work an inexpensive end-to-end-test phantom, which allows for checking the isocenter position on all relevant devices and the dose delivery variations of the treatment chain in radiation therapy, was designed and evaluated.

Materials & Methods
The CAD-drawn and 3D-printed multi-modality end-to-end-test phantom (UMM phantom) was constructed out of solid PA12 walls and a powder-filled interior. To get the compound isocenter deviation of the entire treatment chain the CT-laser center, the center of the surface scanning system, the kV center, the MV center for gantry, collimator and couch rotation and the positional agreement of these centers were measured. Additionally, for the end-to-end-test the check of the CT number to electron density assignment in the treatment planning system and the comparison of the delivered dose at the linear accelerator with the dose expected out of the treatment planning system was performed.

Results
The results of the measurements with the UMM phantom fulfilled the specifications for stereotactic or intensity modulated radiation therapy given in the national protocols. Without including treatments with couch rotation the compound isocenter detected with the UMM phantom was less than 1 mm and the mean dose deviation after performing the whole end-to-end-test was 1.2%.

Summary
A multi-modality end-to-end-test phantom was developed. This phantom can be used to perform an end-to-end-test for the entire treatment chain in radiation therapy. During this end-to-end test the compound isocenter variations for all imaging and delivery systems can be detected. This helps medical Physicists to identify, optimize or adjust isocenter positions for various systems using a single, inexpensive and easy-to-use phantom.
eP38 Quality assurance of a novel, mobile X-ray system for brachytherapy

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Introduction
Cone-beam computed tomography (CBCT) has widely been established during the last 20 years in many medical specialities, as e.g. image-guided brachytherapy (IGBT). An essential element for ensuring high image quality of CBCT examinations at low dose is an extensive quality assurance (QA) of the respective devices, performed both preclinically and regularly next to routine operation. However, to date no QA gold standard has been established for intraoperative and interventional CBCT. The development of a QA procedure for a novel CBCT system forms the work’s scope.

Materials & Methods
Recently a novel, mobile, gantry-based X-ray-system for interstitial and intracavitary brachytherapy became clinically available worldwide for the first time, which is controlled via tablet-PC and allows planar and volumetric imaging with independent movable source and detector. Two such systems have been installed at the involved clinical sites. Dedicated standard phantoms were used for developing in cooperation of both independent sites a QA procedure for checking consistency and adequacy of the device’s image quality with respect to corresponding baselines over time. Imaging performance is investigated regarding uniformity, geometry, CT-number and electron density accuracy, high/low-contrast resolution and behavior, noise, dynamic range, and dose. Partial automation reduced time requirements.

Results
The developed QA procedure allowed a comprehensive characterization of the imaging performance of the examined systems with low time requirements (< 1.5 hours). Both devices showed good geometric accuracy (≤ 0.6 mm), spatial resolution (14 lp/cm, Fig.1), and contrast-noise-ratio at bone-transitions (up to 28:1). Weaknesses appeared examining uniformity, low-contrast differentiability, and artifacts. Improvements are under development by the manufacturer.

Summary
The implemented QA procedure allowed comprehensive performance assessment of the investigated devices. The phantom studies showed an overall good image quality, with weaknesses regarding particularly uniformity and low-contrast differentiability.

Appendix 1

Fig.1: 14 lp/cm were resolved within a dedicated phantom at 0.1mm pixel size.
eP39  Modeling of a medical linear accelerator with the Monte Carlo program package EGSnrc

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Introduction
VMAT treatment plans need to be verified individually before their clinical application – either via measurement or via external Treatment Planning System (TPS). The Monte Carlo model shown here presents an additional option.

Materials & Methods
Based on the manufacturer’s data and using the Monte Carlo code EGSnrc [1], a model of the medical linear accelerator “Synergy” (Elekta AB) was created. One-dimensional dose distributions were simulated and compared to measurement. To achieve a better fit, the model of the “Agility” MLC was further refined.

Results
For quadratic field sizes up to 20x20 cm², the simulated depth dose curves (PDD) and dose profiles show relative deviations less than 1 % from measurements (Figure 1). The beam quality index \( Q \), evaluated under reference conditions (SSD = 100 cm, 10x10 cm²) agrees with measurement within 0.1 %. Moreover, the results of Schaks et al. [2] regarding the investigated shift of \( Q \) in off-axis fields could be confirmed.

Summary
During multiple tests, the model has proven to be sufficiently reliable and can therefore now be used to simulate patient treatment plans.

Appendix 1

Figure 1: Comparison between simulated dose (DOSXYZnrc) and measurement at two Synergy machines with microdiamond (PTW) detector for PDD (SSD = 100 cm, 10x10 cm²).
Appendix 2

Figure 2: Comparison between simulated dose (DOSXYZnrc) and measurement (microDiamond detector) for dose profile (SSD = 90 cm, 3 field sizes).

References


Implementation of the requirements of DIN 6864-1 for checking the overall radiation therapy system in stereotactic applications

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Introduction
The success of radiotherapy treating malignant diseases is due to the use of state-of-the-art radiation techniques with high-tech radiation equipment. However, this requires a sophisticated QA program. In addition to the QA of individual components, the German Strahlenschutz Kommission recommends the review of the whole radiation therapy chain /1/, which was already issued in 2010. A specialized DIN 6864-1 is now available which addresses this question.

Materials & Methods
For this purpose the SRS MapCHECK in combination with the phantom StereoPHAN is used. For the phantom two inserts one for MRI (3 oil resavoirs) and one for CT/CBCT imaging (fiducal markers) are available. These inserts may be replaced by a 2D array without any setup changes of the phantom itself. After CT imaging, a VMAT irradiation plan with three dose levels is calculated based on the oil-filled spheres. For treatment delivery the phantom is positioned on the treatment couch of the linac using CBCT imaging according to DIN specifications including a defined displacement. Dose verification is performed using SRS MapCHECK, which replaces the MR and CT/CBCT inserts required for imaging.

Results
Due to the modular design of the system and the markers integrated in the different inserts, the DIN specifications could be applied without any problems. By replacing the imaging elements with the 2D array, dose verification could be performed in the same setup. The agreement of the dose distributions was above 98 % with an applied gamma criterion of 1 %/1 mm.

Summary
The SRS MapCHECK in combination with the StereoPHAN fulfills all requirements for the implementation of the different test procedures specified in the DIN 6864-1. In addition, the accuracies indication level 1 (highest precision) written down in the SSK recommendation are met.

/1/ Festlegung von Risikoschwellen und Toleranzgrenzen für die Prüfung des Gesamtsystems bei der perkutanen Strahlentherapie mit Photonen und Elektronen, SSK Empfehlung 16.2.2018
Using a TPS Scripting API to increase quality, efficiency and safety in radiation oncology

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Introduction
Der Planungsprozess einer perkutanen Bestrahlungsbehandlung besteht aus einer Kette von arbeits- und zeitintensiven Aufgaben, welche sich grundsätzlich in Konturierung, Bestrahlungsplanung, Planevaluation und Planverifikation unterteilen lassen, wobei die Berufsgruppen Arzt und Medizinphysiker im ständigen Austausch stehen.

Die schiere Anzahl an Entscheidungen und repetitiver Tätigkeiten, die während dieser Prozesse stattfinden, bürgt ein permanentes Risiko für Fehler und das Potential die Effizienz durch Automatisierung zu steigern.

Das erste Ziel dieser Arbeit ist es, die Möglichkeiten von Automatisierung und die Überprüfung dieser Arbeitsschritte durch eine Programmierschnittstelle (API) zum Bestrahlungsplanungssystem (TPS) aufzuzeigen.

Weiterhin kann eine solche Schnittstelle genutzt werden, um mit Hilfe von DataMining von Fällen mit ähnlicher Tumorlokalisation und Dosisverschreibung bei aktuellen oder retrospektiven Fragestellungen zu profitieren.

Materials & Methods
Es gibt mehrere TPS, welche den Benutzern den Zugriff zu einer API gewähren. In unserem Fall verwenden wir die API vom TPS Eclipse (Version 16.1) der Firma Varian (ESAPI). Diese API kann durch die Programmiersprachen C# und/ oder Python angesprochen werden und ermöglicht ein vielseitiges Anwendungsspektrum.

Results
Abbildung 1 zeigt die grafische Oberfläche (GUI) eines klinisch verwendeten und InHouse-programmierten PlanCheck-Programms. Hierbei werden neben der Überprüfung von Dosis-Constraints (siehe PQM-Tabelle) auch automatisierte PlanChecks (siehe PC-Tabelle) durchgeführt, welche sich in die Rubriken Nomenklatur, Dosimetrie, Planparameter, Terminierung und spezielle Flüchtigkeitsfehler unterteilen lassen. Die Anzahl dieser Checks kann abhängig von Zielregion und Bestrahlungstechnik variieren, aber ist meistens dreistellig. Dadurch, dass dieses Programm vom Medizinphysiker im Planungsprozess und vom Arzt bei Planabnahme mehrmals geöffnet wird, konnten die häufigsten Fehler, welche einen Neueinstellungstermin verzögern oder einen Patienten im schlimmsten Fall gefährden würden, vollständig eliminiert werden, wodurch Effizienz, Sicherheit und Planqualität deutlich profitieren.

Zusätzlich bietet PlanCheck die Möglichkeit Pläne zu vergleichen und die Plan-Dokumentation zu automatisieren.

Abbildung 2 zeigt die GUI eines InHouse-DataMiners, welcher es ermöglicht Metriken aller jemals bestrahlten Behandlungspläne innerhalb von Minuten zu generieren, was in Forschung oder der Evaluation aktueller Fälle ein mächtiges Tool sein kann und ansonsten nahezu unmöglich wäre. Zusätzlich können DICOM-Exports von Patienten-Kohorten, welche anhand von IDs oder Planparametern gefiltert werden können, automatisiert werden.

Summary
Figure 1: Grafische Oberfläche eines für die Klinik-internen Bedürfnisse angepassten PlanCheck-Programms.
Joint Conference of the ÖGMP, DGMP and SGSMP

Figure 2: Grafische Oberfläche eines für die Klinik-internen Bedürfnisse angepassten DataMining-Programms, welches Eclipse und individuelle Metriken extrahieren kann, wobei auch Möglichkeiten zum DICOM-Export gegeben sind.
In-house production of a head phantom for end-to-end testing of the radiotherapeutic chain

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Introduction
In the quality assurance of teletherapy, the verification of the total error of the radiotherapeutic chain is of great importance. The implementation for checking the dosimetric and geometric uncertainty according to DIN 6864-1 and especially for stereotactic treatments according to DIN 6875-1 was realized with an in-house manufactured, equipment-specific head phantom.

Materials & Methods
The three-part head phantom is manufactured using a stereolithographic 3D printer (Form 3, Formlabs). All sub-steps of the radiotherapy process are included in the system test. The anthropomorphic phantom enables a patient-equivalent representation of the irradiation process, including individual positioning equipment.

The absolute dosimetric accuracy is determined with an ionization chamber suitable for small-field dosimetry (PinPoint 31006, PTW), for which a cavity was modeled in the head phantom. The geometric accuracy was determined with Gafchromic film. To fulfill both DIN 6864-1 and 6875-1, two different treatment plans are created. One test is performed with a normofractionated plan with homogeneous dose distribution, normalized to the mean target dose. Another test is performed with a stereotactic plan with a correspondingly inhomogeneous dose distribution and steeper dose gradient to account for the effects of small-field dosimetry.

Results
Both treatment plans showed a slight underdosage compared to the planned dose. On average, the total dosimetric error amounted to 2.3 % for the normofractionated and 2.9% for the stereotactic plan. The geometric uncertainty, determined by comparing the dimensions of the 50% isodose lines, was on average less than 1 mm for both plans.

Summary
The production of an equipment-specific phantom by means of 3D printing is a cost-effective way of performing a test of the overall radiotherapeutic system (end-to-end test) using the individually available measurement equipment.
An optimised LINAC-emulator for VMAT treatment time prediction

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Introduction
Inverse treatment planning systems typically do not provide realistic information about the treatment time \( T \) for a given linear accelerator (LINAC). We developed a LINAC-delivery emulator predicting \( T \) based on DICOM-RTplan files.

Materials & Methods
We developed a parameterized approach originating from Boylan et al. [1] fitting the emulator output with real LINAC (VersaHD, Elekta AB, Sweden) data. With the control point interval (CPI) specific monitor units \( (MU) \), gantry arc length \( (\Delta \Theta) \) and maximum distance of leaves and jaws \( (\Delta L_i, \Delta J_i) \) the delivery time \( (t_{\text{emulator}}) \) is determined by

\[
t_{\text{emulator}} = \sum_{i=1}^{\#\text{CPIs}} \max \left( \frac{MU_i}{DR_i} \frac{\Delta \Theta_i}{\Omega_i} \frac{\Delta L_{i,\text{max}}}{v_L} \frac{\Delta J_{i,\text{max}}}{v_J} \right)
\]

Loading times are added for initial \( (t_{\text{init}}) \) and turning points \( (t_{\text{TP}}) \). The model parameters dose rate \( (DR) \), gantry rotation speed \( (\Omega) \), MLC leaf and jaw speed \( (v_L, v_J) \) as well as the loading times are obtained by fitting \( t_{\text{emulator}} \) to LINAC logfile data \( t_{\log} \) using

\[
f = \frac{100}{\#\text{Training Plans}} \sum_{\#\text{Training Plans}} |t_{\text{emulator}}/t_{\log} - 1|
\]

as objective function. To minimize \( f \) we used differential evolution [2]. 111 volumetric modulated arc therapy (VMAT) treatment plans of different entities with 6MV and 10MV flattened beams are used for 4-fold cross-validation.

Results
Cross-validation parameter results are summarized in Tab 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v_L ) (mm/s)</td>
<td>37.01 ± 0.35</td>
</tr>
<tr>
<td>( v_J ) (mm/s)</td>
<td>31.65 ± 0.72</td>
</tr>
<tr>
<td>( \Omega ) (°/s)</td>
<td>5.93 ± 0.03</td>
</tr>
<tr>
<td>( DR ) [6MV] (MU/s)</td>
<td>9.28 ± 0.06</td>
</tr>
<tr>
<td>( DR ) [10MV] (MU/s)</td>
<td>8.73 ± 0.05</td>
</tr>
<tr>
<td>( t_{\text{init}} ) (s)</td>
<td>3.16 ± 0.35</td>
</tr>
<tr>
<td>( t_{\text{TP}} ) (s)</td>
<td>1.82 ± 0.60</td>
</tr>
</tbody>
</table>

Table 1: 4-fold cross-validation: cycle averaged parameter values with standard deviation

The mean deviation between \( t_{\text{emulator}} \) and \( t_{\log} \)

\[
\mu = \frac{100}{\#\text{Test Plans}} \sum_{\#\text{Test Plans}} (t_{\text{emulator}}/t_{\log} - 1)
\]

is calculated for each cycle, where \( \sigma \) is the corresponding standard deviation. The cycle averaged values are \( \mu = (0.07 ± 0.42)\% \) and \( \sigma = (1.61 ± 0.17)\% \).

Summary
The deviation between \( t_{\text{emulator}} \) and \( t_{\log} \) is expected to be less than \( 2\sigma = 3.22\% \) with a small bias of \( \mu = 0.07\% \) in overestimating \( T \). The emulator can be used for optimizing time critical treatments or monitoring machine specific parameters.
References


Introduction
The Monte Carlo model presented in a different poster [1] was modified to allow for verification of clinical Volumetric Arc Therapy (VMAT) plans.

Materials & Methods
The EGSnrc [2] accelerator model was converted to a synchronized version. MU calibration was implemented and tested. In order to simulate VMAT treatment plans, a python script extracts relevant information from the RTPLAN DICOM-file and transforms it to an EGS-interpretable syntax. Plan verification is possible based on virtual phantoms or CT-based phantoms. An evaluation with 3D Slicer [3] allows for comparison between simulated dose distribution and RTDOSE distribution from the TPS in terms of difference plots, gamma evaluation, dose volume histograms and ROI evaluations.

Results
Comparison of calculated dose distributions (TPS) with simulations by means of gamma evaluation (3 % dose difference/3 mm distance to agreement) typically displayed pass rates of more than 95 %. Figure 1 shows the result of a thyroid plan simulation. Gamma evaluation yielded a pass rate of 97.5 %.

Summary
During multiple tests, the model has proven to be sufficiently reliable and can therefore now be used to simulate patient treatment plans.

Appendix 1

Figure 1: a) Simulated dose distribution, b) reference dose distribution (TPS), c) difference plot, d) gamma map [3]
References

eP45  Absolute dosimetry with PMMA phantoms for stereotactic treatment application

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Introduction

For practical reasons, measurement phantoms made of solid materials are used in radiation therapy in addition to water phantoms. When selecting these materials, dosimetric equivalence must be considered. Due to different radiation transport properties of the materials, this is not always given. The aim is to develop a concept to directly compare absolute dose measurements in polymethyl methacrylate (PMMA) with calculated dose values of the therapy planning system.

Materials & Methods

Two approaches were followed. First, the phantom dose conversion factor was determined according to the procedure described in [1]. This involves relating the absorbed dose in water at the reference depth to the absorbed dose in PMMA at the equivalent depth. On the other hand, dose values are calculated using the algorithms AAA and Acuros XB (Varian Eclipse) with different density values in the therapy planning system and compared with measurements in PMMA.

Results

The phantom dose conversion factor for PMMA depends on field size and measurement depth. At smaller measurement depths, the factor is similar for all field sizes. As the measurement depth increases, the value diverges so that it remains constant at small field sizes and steadily decreases as the field size increases. Calculations of dose values using Acuros XB did not produce uniform agreement with the measured values. Calculations using the AAA algorithm and a density of 1.19 g/cm³ agreed closely with the measured results, with a mean deviation of 0.06 %.

Summary

A suitable method for comparing measurements in PMMA with the TPS is provided by calculating dose values using the AAA algorithm and a density of 1.19 g/cm³. The agreement of the dose values is very high, and the metrological effort is very low compared to the determination of the phantom dose conversion factor according to TRS 483.

Dosimetric end-to-end test for intrauterine brachytherapy in a water phantom

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Introduction
In intrauterine brachytherapy, dose is prescribed as D₉₀ to the edge of a clinical target volume having a diameter of typically 4 cm. A dosimetric end-to-end test was designed to check the dose to a point pair in 2 cm lateral distance from the applicator in a water phantom.

Materials & Methods
A Venezia applicator (Elekta) mounted on a PMMA holder was imaged with a CT-scanner and imported into Oncentra Brachy (Elekta) treatment planning system. After library-based applicator reconstruction, a standard treatment plan was created according to clinical routine. TG-43-dose was normalised to a point pair halfway between tandem tip and lunar ovoid plane with 2cm lateral distance from the tandem axis. After export to the afterloader (MicroSelectron Digital, Elekta), the plan was irradiated at least three times while dose was measured at each of the two dose points in a water phantom (PTW MP3). For measurements, a 0.016 cm³ PinPoint3D ionisation chamber (PTW) was mounted on the PMMA holder with its axis in the same height but perpendicular to tandem axis. Using a spacer between tandem and chamber tip, chamber reference point was set on either side of the tandem to the location of the dose point. For both calculated and measured dose, an uncertainty budget was set up.

Results
By taking the mean between dose measurements left and right of tandem, uncertainty can be reduced. In three independent tests, measurements were well within tolerance levels.

Summary
A stable and robust dosimetric end-to-end test for intrauterine brachytherapy with a Venezia applicator using a PinPoint3D chamber for dose measurements in a water phantom was established.

Appendix 1

Figure 1: Measured dose normalized to calculated plan dose at points left and right of tandem, and mean dose for three independent test measurements. Green shaded (tolerance) area represents uncertainty of calculated plan dose (k=1).
Non-invasive input function measurement device for PET or SPECT based on novel YSO scintillators

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²SMI / Austrian Academy of Sciences, Vienna, Austria

Introduction
Activity measurement of the injected radiotracer is important for the absolute quantification of diagnostic images like for example PET/CT or SPECT/CT. For instance, compartmental kinetic modeling allows interpretation of the radiotracer underlying biochemical processes, and, therefore, leads to a better understanding of organs behavior and diseases. Since tracer uptake and metabolization is a dynamic process, an exact knowledge of its behaviour in the blood pool is mandatory. The gold standard is to derive input function from arterial blood sampling, which is both challenging and dependent on corrections. We developed a miniature non-invasive input function measurement device with modular structure and characterized it in the pre-clinical environment with mice. Our non-invasive approach facilitates high precision, good temporal resolution and allows longitudinal PET/SPECT studies.

Materials & Methods
The device is based on an intrinsic background-free fast yttrium orthosilicate (YSO) inorganic scintillator readout by a silicon photomultiplier (SiPM) connected to a multichannel digital counter. The device has a modular structure and several portable shielded-collimated modules can be read out simultaneously. Readout electronics has a capability to set up an energy threshold and to adjust sampling frequency. Specification of the device makes it suitable for both clinical and pre-clinical applications without further hardware modifications.

Results
The developed non-invasive gamma counter has linear response up to 600 keV and is free of intrinsic background. It makes it suitable for PET as well as SPECT studies with radiopharmaceuticals emitting gamma radiation between 100 and 600 keV. Detector design allows sampling intervals to be as short as a few microseconds, does not require any surgical procedure and has a good signal to noise ratio. We successfully performed ¹⁸F – FDG bolus injection studies with mice. We show the importance of a standardized bolus injection procedure and its strong influence on the fit parameters relevant for the dynamic kinetic modeling. Influence of the measurements duration on fit parameters is presented and optimum measuring time is discussed.

Summary
The developed non-invasive input function measurement device is based on novel YSO scintillators which are free of intrinsic background. Placement of the detector over the subject does not require any surgical procedure, and can be an easy to adopt replacement for the devices that require invasive procedures. No subject termination is required thus allowing longitudinal studies. We show that to obtain reliable fit parameters bolus administration must be performed as fast as possible. It is essential to measure the first 25 min in order to obtain reasonable fit parameters.
Irradiation with protons allows for highly conformal dose distribution in tumors while sparing healthy tissue to a large degree, which is of particular importance for brain irradiation. Nonetheless, elevated dose levels in the distal regions can lead to severe late side effects, causing cognitive impairment and an overall reduced quality of life. Preclinical data regarding the underlying biological mechanisms of such effects, however, remain insufficient due to the technical demand of such experiments and the scarcity of suitable research facilities. To address this problem, we present the open-source dataset Slice2Volume (https://rodare.hzdr.de/record/915), which contains registered, multimodal imaging data of nine mice that received high-precision proton brain irradiation with different doses in a clinically relevant setting.

The dataset comprises baseline computed tomography (CT), Monte-Carlo simulated distributions of dose and linear energy transfer (LET), a mouse brain atlas, up to six months of magnetic resonance imaging (MRI) follow-up. In addition, we provide whole-brain histological sections with eight registered stainings of all major brain cell types (neurons, astrocytes, microglia, myelin), as well as markers for proliferation, cell nuclei, general morphology (H&E) and the Nestin protein. We used the self-developed tool Slice2Volume as well as the existing methods Elastix and Big Warp to fuse all image data, so that all modalities can be freely overlaid.

The provided image data allows establishing correlations and mechanistic observations regarding effects of proton radiation on the clinical (MRI, dose) and the microscopic level and thus drawing conclusions regarding the involved cellular processes. The inclusion of dose and LET allows elucidating the latter’s relation to biological effects with high statistical leverage. Lastly, we provide all used parameter files and code for the Monte-Carlo simulation and the image registration, respectively, so that conclusions drawn from this dataset can be readily reproduced or validated by the scientific community.
eP49 Validation of positioning accuracy for cranial treatments: optical surface/thermal and X-ray imaging

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Introduction
The ExacTrac Dynamic (Brainlab AG, Germany) provides 3D surface information by combining optical and thermal imaging along with an in-room kV X-ray imaging system.
We aimed at comparing the positioning accuracy of combined surface/thermal imaging and the gold-standard, stereoscopic X-rays, for stereotactic radiosurgery treatments with a head phantom with a specific heat signature.

Methods
An anthropomorphic 3D-printed head phantom (Prime, RTsafe, Greece) with bone equivalent material and 3 embedded ball bearings was filled with water. It was fixed to the table using a 4Pi open face mask (Brainlab AG, Germany).
To investigate the phantom’s surface temperature stability, warm water (41°C) was used and surface temperature measured with an infrared thermometer within the area of the face opening (Fig. 1).
The surface/thermal (DS+T) and X-ray positioning (DXRAY) were measured at a linac (Elekta, Sweden). The couch (0°) was displaced in 3 directions from the planned position (25 translations). A room temperature water (cold) and a warm water filled phantom were used. The difference between positioning methods ($\Delta D_{\text{POSITION}} = |D_{\text{XRAY}} - D_{\text{S+T}}|$) was calculated and significance assessed with a Mann-Whitney U test.

Results
Fig.1 shows temperature stabilisation 10 minutes after filling and during the next 55 minutes. In most locations temperatures were between 36°C and 32°C after 1h. The 4°C difference is not expected to impact the measurements.
Tab.1 reports the couch translations and the difference between both positioning methods. Statistically significant differences between the positioning of cold and warm phantom in lateral and longitudinal directions were found ($p < 0.05$).

Conclusion
The measurements with a warm phantom showed good agreement between both positioning methods (max. deviation 0.2mm). Measurements with a cold phantom showed slightly higher deviations (max. deviation 0.7mm) with statistically significant differences in two directions.

Appendix 1:

Figure 1: A –Surface temperature measurement locations (a – g). B –Temperature vs. time.
Appendix 2:

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<th>$\Delta D_{\text{POSITION}}$ (warm) (mm)</th>
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Mean (mm): 0.22, 0.08, 0.10
Standard deviation (mm): 0.18, 0.05, 0.08

Table 1: Couch translations ($\Delta D_{\text{COUCH}}$) and differences between surface/thermal and X-ray positioning ($\Delta D_{\text{POSITION}}$).
Introduction
This study aimed at investigating a 4DCBCT scatter-correcting algorithm, using a 4D virtual CT (4DvCT) as prior, for usability for time-resolved proton dose calculation of lung tumours.

Materials & Methods
4DCBCT and 4DCT scans of an ex-vivo porcine lung phantom with four injected artificial lesions were both acquired with different breathing patterns (planning, day-of-treatment). The average planning 4DCT was rigidly registered onto the FDK reconstructed day-of-treatment 3DCBCT. Using a Morphons algorithm a 4DCT mid-position image was registered onto a 4DCBCT mid-position image, obtained using MA-ROOSTER. The resulting 4DvCT, assumed to be scatter-free, was forward projected. These forward projections were exploited on a phase-per-phase level to scatter correct the corresponding CBCT projections. Applying MA-ROOSTER on the corrected projections with the same settings and deformation vector fields used for the 4DCBCT reconstruction yielded the 4DCBCT_cor (Fig.1).

4DvCT and 4DCBCT_cor were dosimetrically evaluated by comparing proton dose calculations in terms of DVH and gamma pass-rate versus the reference 4DCT for individual phases and accumulated doses.

Results
DVH parameters deviated at most 2.0% in the 4DCBCT_cor and 1.7% in the 4DvCT case (Fig.2). The 2%/2 mm gamma pass-rates with a 10% threshold were at least 93.2% (4DvCT) and 94.2% (4DCBCT_cor). Additional analysis showed mean errors in HU for the contours body, lung, and surrounding shell of 20HU, 10HU, and 10HU in the 4DvCT case and 25HU, 10HU, and 10HU in the 4DCBCT_cor case, respectively.

Summary
The qualitative and quantitative agreement showed the usability of 4DCBCT_cor and 4DvCT for accurate time-resolved proton dose calculation, which indicates the potential for daily 4DCBCT-based treatment planning.

Acknowledgments
DFG
Fig. 1: Left: Proposed 4DCBCT scatter correction workflow. Right: CTs of the different breathing motion amplitudes planning (plan) and day-of-treatment (ref).

Fig. 2: Proton dose calculations of ITV₄ and corresponding dose-volume-histograms (DVHs) for the maximum exhale phase as well as the accumulated dose.
eP51 Interrater variability in clinical studies – a study on Pulmonary Artery Embolism (PE) diagnosis with V/P-SPECT/CT

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2University Hospital RWTH Aachen, Nuclear Medicine, Aachen, Germany

Introduction
This study aims to determine the inter-rater reliability between two raters using Cohen’s kappa (k) to investigate a reliable visual clinical diagnosis within the scope of a semi-automatic evaluation.

Materials & Methods
Retrospectively, n=200 patients received a V/P-SPECT/IdCT1 and were evaluated by two raters. For rater 1, a binary dichotomous grading was given (score 0: no PE; score 4: clear PE). For rater 2, a five-level weighted score was given (score 0: no PE, score 1: probably no PE; score 2: equivocal, score 3: probably PE; score 4: clear PE), which was converted into a binary scoring by setting the PE threshold to either score 2, 3, or 4. To investigate the common agreement, Cohen’s kappa evaluation was performed for different classifications of the entire lung as well as for the five individual lung lobes. Additionally, the confidence interval (CI: 95%) as well as the sensitivity (Se) and specificity (Sp) of both raters were determined and evaluated. Se and Sp were calculated to provide more information about the diagnosis robustness in case of unequal distributions of the contingency tables.

Results
The largest agreement between the raters was found in classification II with a PE ratio of 25 % (n=49) for rater 1 and 27 % (n=54) for rater 2. An entire lung analysis resulted in k=0.75 with CI (95 %): [0.68-0.82] with rater 1 (Se=0.76, Sp=0.98) and rater 2 (Se=0.79, Sp=0.97). A single lung lobe analysis resulted in k(RUL)=0.71, k(RML)=0.71, k(RLL)=0.86, k(LUL)=0.74, k(LLL)=0.73.

Summary
New techniques require comprehensive analysis. The prior methodology shows that classification II is suitable as a criterion standard for further analysis. There was no significant difference between the analysis of total and single lobes. Sensitivity and specificity are not significantly different between the two raters. The numerically quantified evaluation revealed that the raters performed the classification according to PE size criteria.

Appendix 1

![Figure 1: Score distribution of the physician’s visual findings (Rater 1)](image1)

![Figure 2: Score distribution of the physician’s visual findings (Rater 2)](image2)
### Appendix 2

**Table 1: Classification I**

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**Table 2: Classification II**

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**Table 3: Classification III**

### References

eP52  Head to head comparison of three phantoms used for MRI QA in radiotherapy

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Introduction
Due to the rising importance of magnetic resonance imaging (MRI) in radiotherapy, one has to think about quality assurance of the MRI as a part of the radiotherapy treatment planning process.

Material & Methods
The RUBY phantom (PTW-Freiburg), the Lucy phantom (Standard Imaging) as well as a self-developed combination of both phantoms (LUBY) were used to evaluate the image registration process between MRI data of a Siemens-Avanto-1.5T-MRI and computer tomography (CT) data of a Phillips-Big-Bore-CT. To assess the quality of the registration test volumes inside the phantoms were analysed visually in Varian Eclipse (V16.1). Afterwards, they were delineated in the MRI and CT datasets independently and compared. Geometric accuracy and distortion of the Lucy and LUBY images were evaluated according to the AAPM TG 284 report.

Results
Visually there are no considerable differences between the test volumes in the MRI and CT datasets of the three phantoms (figure 1). For RUBY, Lucy and LUBY the mean volume differences of the delineated test volumes differ less than 7.2 %, 1.1 % and 2.2 % between the MRI and CT datasets as well as from the manufacturer specifications. Because of the length of its test volumes, RUBY allows the detection of a signal loss at the edges of MR scanning volumes. With Lucy and LUBY the geometric accuracy and distortion for distances from 0.50 up to 8.72 cm were determined within the geometric resolution.

Summary
For the quality assurance of the MRI in radiotherapy all phantoms are suitable for a visual comparison between MRI and CT data. Furthermore, RUBY can be used to evaluate the homogeneity of the MRI signal, whereas Lucy and LUBY allow the analysis of geometric accuracy and distortion of the MRI and CT images.

Appendix

Figure 1: MRI-CT image registration of RUBY, LUBY and Lucy
A bone suppression method to improve tumour motion monitoring in intensity-based 2D/3D registration

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Introduction
In radiotherapy, accurate dose delivery to tumours located near the diaphragm is compromised by respiration-induced motion. Motion management requires real time tumour motion monitoring (TMM). However, TMM can be difficult if the target is located behind bony structures. The aim of this work is a proof of concept of a novel bone suppression method for a 2D/3D marker-less TMM algorithm.

Materials & Methods
A real time bone suppression method based on the subtraction of bony structures rendered from CT data and subtraction from intra-fractional X-ray images after intensity adaptation was implemented in the in-house developed software for intensity-based 2D/3D tumour registration (FIRE). Its accuracy was validated by simulation of 5 cm cranio-caudal tumour motion within an in-house developed breathing phantom. X-ray images of the tumour in different positions were acquired. The mean intensity values of six regions of interest (ROIs) within bone segments, six ROIs in lung segments and one ROI in the tumour were used to evaluate contrast.

Results
A comparison of original and bone suppressed X-ray images showed that local maxima in the intensity line-profiles caused by ribs (blue line) could be removed successfully (flat red line outside of the tumour section). As a result, TMM succeeded in all cases when ribs were suppressed with a registration error of 1.52 mm for RMSE and 1.27 mm for MAE. Using the original X-ray images without bone suppression registration failed as the optimizer got stuck in local maxima.

Summary
The proposed bone suppression method allowed accurate TMM when the tumour was eclipsed by the ribs in an anthropomorphic lung phantom. These promising results need to be validated with a patient study to evaluate benefits in clinical practice.
Appendix 1

Figure 1 - a) Intensity line profile across tumour region (position 70 ... 90) of original (blue) and bone-suppressed (red) X-ray image. Tumour and edges of ribs are marked with arrows, a, b, c. Region of interest of X-ray image from ARDOS phantom before bone-suppression (b) and after bone-suppression (c).
Dosimetric evaluation of surface-based intrafractional motion during breast cancer radiotherapy treatment

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Introduction
In this study, an analysis of dosimetric effects of intrafractional motion during the treatment of breast cancer patients, as evaluated by SGRT, is carried out. The necessity of SGRT-based gated treatment is assessed and suitable monitoring threshold values are determined.

Materials & Methods
Patients are treated on two C-arm linacs equipped with a SGRT system. After positioning using either SGRT only or additional CBCT scans, patient movement during treatment is recorded using the surface scanner. The motion is analysed statistically and a probability distribution of the shifts is created. Dose calculations with different shifts are carried out with the treatment planning system. On one hand, using a sample of motion patterns obtained from the probability distribution, a representative dosimetric effect is calculated and used to access the impact on target coverage and OAR dose. On the other hand, maximum shift values are determined using dosimetric thresholds with the objective of obtaining suitable monitoring threshold values for application during treatment.

Results
A first dosimetric analysis with predefined shifts showed significant deviations from originally planned dose distributions for shifts slightly above standard SGRT monitoring threshold level (0.3 cm). For one patient, target coverage was reduced from 95.3 % to 83.1 % for a shift of 0.4 cm in two degrees of freedom, while maximum heart dose increased from 32.3 Gy to 45.7 Gy and V₂₀ of the ipsilateral lung from 19.3 % to 23.7 %. This highlights the necessity of further investigating the dosimetric impact of intrafractional motion with the use of the observed shifts, which currently is undertaken.

Summary
Dosimetric effects of intrafractional motion during treatment of breast cancer patients is evaluated using shifts obtained from SGRT for dose calculations based on the original treatment plans. The results indicate that continuous SGRT-based gating during treatment might be necessary for correct delivery of planned dose distributions.
Introduction
Image guided radiation therapy (IGRT) improves the precision and accuracy of the treatment delivery, providing information for correct set-up as well as of patient anatomy during the total treatment period. Daily Cone-beam computed tomography (CBCT) images can therefore be used to detect anatomical changes with respect to the planning CT (pCT) and, possibly, to determine the accumulated dose and compare it to the planned one. To this purpose, an accurate deformable image registration (DIR) algorithm between daily CBCT and pCT should be available, since its quality affects the overall uncertainty of the accumulated dose.

Materials & Methods
Daily CBCT images of four prostate cancer patients undergoing a 28-fraction irradiation plan, with appreciable bladder and rectum volume variations, were used in this work. For each patient, the rectum and the urinary bladder were manually contoured on these images. Image data sets were then registered into the pCT using an in-house B-spline-based deformable registration algorithm and the registration performance was validated by calculating the dice similarity coefficient (DSC) and the Hausdorff distance (HD) for the contoured organs at risk.

Results
Among the four patients analysed so far, with a focus on the days where bladder and rectum volume deviation were more than 50 % with respect to the reference, the DSCs varied between 0.37 and 0.66 and the HD values were approximately 23±10 mm. However, for slight deviations of the organ volumes from the reference volumes, the DSCs reached values between 0.8 and 0.9 with HD values of 13±6 mm.

Summary
For small organ deformations, the developed registration algorithm ensures an acceptable deformation of the contoured structures. However, large changes in the geometry of the organs affect the implementation of the DIR. A method is being developed to estimate the accumulated dose in a conservative way, thus taking into account for DIR-related uncertainties.
eP56 Fast dose calculations for novel radiotherapy treatments with generative adversarial networks

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Introduction
Existing approximations used in clinical treatment planning are either not fast or not accurate enough for some novel irradiation techniques like microbeam radiation therapy (MRT), which relies on arrays of sub-mm synchrotron-generated, polarized X-ray beams. We present studies using generative adversarial networks (GANs) to mimic full Monte Carlo simulations of radiation transport to achieve a compromise of fast and accurate dose computation for variable phantoms and irradiation scenarios.

Materials & Methods
To obtain a generalised model for the dose prediction a conditional GAN using a 3D-UNet architecture is developed. As proof of concept, we predict the simulated dose depositions of a bone slab inside a water phantom with variable rotation angles and thicknesses. Subsequently, we demonstrate that our model is generalisable by applying it to a simplified head phantom simulation. All Monte Carlo simulations are performed with Geant4 using a phase space file obtained from a validated simulation at the Australian Synchrotron.

Results
The trained model predicts for both the bone slab inside the water phantom and the simple head phantom dose distributions with deviations of less than 1 % of the maximum dose for over 94 % of the simulated voxels in the beam. Dose predictions near material interfaces are accurate on a voxel-by-voxel basis with less than 5 % deviation in most cases. Dose predictions can be produced in less than a second on a desktop PC compared to approximately 50 CPU hours needed for the corresponding Geant4 simulation.

Summary
The presented ML model can be trained on Geant4 simulation data to generate accurate dose predictions in our experiments consisting of a bone slab in water and a simple head phantom. In future studies we want to include the model towards a treatment planning system for MRT. The presented approach can likely be adapted for other novel treatment methods as well.
Impact of automatic organ segmentation on dose optimization in IMRT for prostate patients.

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Introduction
Automatic segmentation algorithms are commonly evaluated using metrics like Dice Similarity Coefficient (DSC) or Hausdorff distance (HD). However, dosimetric evaluation, showing higher clinical relevance, should be prioritized. Here, we examine the influence of automatic delineation in pelvic CT images generated by a state-of-the-art 3D-Unet on dose optimization in IMRT.

Materials & Methods
Prostate, bladder, and rectum were delineated in 69 CT images constituting a dataset for single-label 3D-Unet training with DSC loss. Single-arc VMAT plans were created for both manual and automatic delineations. Dose distributions were evaluated with the manual segmentation as reference using dose-volume histogram (DVH) parameters and a 3%/3 mm T10% gamma-criterion. For the prostate D98/2% and V95%, were determined while V50/65/70Gy and V60/65/70Gy for the rectum and bladder, respectively. Additionally, DSC, average, and 95% HD have been calculated.

Results
The average DSC was 0.87(1) 0.97(1), 0.89(1) while the average and 95% HD, 1.6(2)/4.2(1.1) mm, 0.95(3)/2.5(3) mm, 1.4(4)/5(12) mm for prostate, bladder and rectum, respectively. Representative image slices with calculated dose distributions are shown in Fig.1. The average gamma-pass rate was determined to be 85%. The DVH parameters (Figure 2), show satisfactory agreement between dose distributions, with the exception of one case.

Summary
For 3D-Unet segmentation, we highlighted the importance of dosimetric evaluation over standard geometric parameters and observed sufficient accuracy of the majority of the autosegmentation.

Acknowledgments
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Figure 1: Dose distributions showing the highest (left) and the lowest (right) gamma-pass rate for plans optimized on the manual (top) and 3D-Unet segmented images (middle). Ground truth (solid) and 3D-Unet-predicted (dashed) contours are shown.
Figure 2: DVH parameter differences for plans optimized using Unet- and manually-generated contours: (a) bladder and rectum, (b) target volume (prostate, prostate + 3 mm margin). The total dose was 74 Gy.
Applicability of a pre-trained neural network for the deconvolution of independent ionization chamber-measured dose profiles in small photon beams

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Introduction
Dose profile measurements with ionization chambers benefit from the chambers’ low energy dependence. However, the volume effect, consisting of the volume-averaging effect and the density perturbation, leads to broadening of the penumbra regions and causes underestimation of the output factors in small fields. In this study, a feedforward three-layer neural network (NN) is used to correct the volume effect associated with ionization chamber-measured dose profiles. The applicability of a pre-trained model to deconvolve measured profiles at a different linac using a different scanning system has been evaluated.

Materials & Methods
A feedforward three-layer NN as proposed by Liu et al. (2018) was trained using lateral 6 MV beam profiles of a Siemens Artiste linac. The training data was acquired for nominal field sizes between 0.3 x 0.3 cm² and 4 x 4 cm² in four depths. A SNC 125c (0.108 cm³) ionization chamber and a PTW 60019 microDiamond detector as the reference detector were used with a PTW MP3 water phantom in stepwise scanning mode. Independent test data was collected at an Elekta Synergy linac with the same SNC 125c ionization chamber and a SNC EDGE diode detector as reference using a Sun Nuclear 3D Scanner water phantom in continuous scanning mode. The independent test data was deconvolved with the pre-trained NN. The results were evaluated using 1D gamma analysis (0.5 mm / 0.5 %) with 5 % threshold.

Results
The profiles from the independent test data set show good agreement with the diode reference profiles after deconvolution using the pre-trained NN. The overall gamma passing rate increases from 39.34% before deconvolution to 77.90 % after deconvolution.

Summary
The results demonstrate the applicability of a pre-trained NN for the correction of the volume effect associated with ionization chamber-measured profiles of small photon fields acquired using independent delivery and scanning systems.
Introduction
MR guided proton therapy is a topic of rising interest, for which developments on dosimetry will be necessary for clinical application. In this work, we aim to investigate the chamber specific correction factors for dosimetry of protons in a magnetic field by means of Monte Carlo simulations.

Materials & Methods
The chamber responses of the PTW30013, used as validation with literature, and five custom built Farmer type ionization chambers with varying cavity radius are investigated. A perpendicular magnetic field was applied locally in the chamber volume to account for changes in the chamber reaction alone, neglecting proton deflection. In addition, the chamber specific factors \( f_Q \) and \( f_{Q0} \) were calculated for the beam quality correction. The dose deposition in the cavities for the \( ^{60}\text{Co} \) reference beam were calculated with the Monte Carlo toolkits EGSnrc and TOPAS and for proton beams of 150, 200 and 250 MeV with TOPAS.

Results
The \( f_Q \) and \( f_{Q0} \) for the PTW30013 in the absence of a magnetic field agree within \((0.25\pm0.14)\%\) with values in the literature for a similar setup[1]. The \( p_Q \) from the resulting beam quality correction deviates from unity by \(1.4\%\) for the PTW30013. The magnetic field with varying field strength up to \(1.5\text{T}\) changed the dose response at most by \((0.36\pm0.23)\%\) and showed a smaller effect on larger chambers.

Summary
The beam quality correction factors that enable the investigated ionization chambers for proton dosimetry experiments were calculated. The found deviation of \( p_Q \) from unity supports the motion to update the TRS398. The effect of the magnetic field on the chamber response was found to be minor. Future work will evaluate the \( k_{BQ} \) of the chambers for dosimetry in magnetic fields.

References
eP60 Investigating the feasibility of TOPAS-nBio for Monte Carlo track structure simulations of GEANT4-DNA example applications

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Introduction
The purpose of this work is to investigate the feasibility of TOPAS-nBio for track structure simulations using tuple scoring and ROOT/Python-based post-processing.

Materials & Methods
Low-energy examples of track structure simulations, first published and analyzed by Incerti et al. [1], as they are included in GEANT4 were re-calculated with TOPAS. The results of both codes were compared to each other. The simulations contained investigations of different physics lists, calculation of energy-dependent range, stopping power, mean free path and w-value. The implementation of the examples in TOPAS was particularly interesting since the examples are not pre-programmed and no corresponding scorer is available. In TOPAS-nBio a tuple scorer was applied to save all relevant tracking information that were post-processed using ROOT and Python.

Results
In Figure 1, calculated ranges of electrons, protons and alpha particles simulated with GEANT4 and TOPAS as well as the deviations are shown. Considering electrons, large relative deviations can be observed at small, absolute ranges. For electron energies above 500 eV, deviations are smaller than 2 %. Comparing proton ranges, deviations are high since different tracking cuts were used in both codes.

Considering the additional simulations, in most cases, the deviations of TOPAS-nBio and GEANT4-DNA are smaller than 5 %. Thus, we have presented a feasible way to implement the example applications included in GEANT4-DNA in TOPAS-nBio.

Summary
With our results we could show the potentials of applying the tuple scorer in TOPAS-nBio Monte Carlo track structure simulations. Using this scorer, each relevant information of the track structure can be accessed, which can be analyzed as preferred after the simulation.
Appendix 1

![Figure 1: Particle range simulated with GEANT4-DNA and TOPAS-nBio.](image)

References

eP61 Evaluation of a prototype detector array for the daily quality assurance in proton therapy

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Introduction
Aim of this study is to verify a prototype detector array for particle therapy, the "Daily QA-P" of the Sun Nuclear Corporation (Melbourne, USA). The array is designed to verify the position, width and range of proton pencil beams (PB) in daily routine quality assurance (QA). This is achieved by a unique layout of ionization chambers: a central chamber surrounded by four others.

Materials & Methods
The measurements were executed with proton and carbon ion pencil beams. The studied parameters were the PB shift in x/y direction, respectively, the change of the PB spot-size and the energy range. The measurements were analysed to correlate a change in the ionization chamber signal to the varied parameters.

Results
Via a calibration measurement, the spot-size (FWHM), as well as the spot shift (in mm) could be determined:
A measure for the spot-size is established, that correlates the FWHM of the PB and the array signal. When the FWHM increases, the array-specific spot-size value also rises (Fig.1). Furthermore, a proportional relation between the PB shift and the change of the signal of the outer ionization chamber was measured (within a 2 mm shift). When the distal fall-off of the PB lies in the effective point of measurement, the signal was very sensitive to energy variation.
The prototype shows a high sensitivity throughout the different tests: Submillimetre changes were found to be distinguishable for the PB shift, the spot-size variation, as well as for a change in energy. In an evaluation over multiple days the consistency of the parameters was verified against an established baseline (Fig.2).

Summary
The Daily QA-P is a prototype array for proton therapy. It offers a fast and digital way to determine and track the position, width and energy range of the beam in routine QA measurements.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure2.png}
\caption{Spot-size measurements}
\end{figure}
Figure 3: Shift measurement
Expansion of a small-animal proton CT reconstruction framework and studies of energy-dependence of relative stopping power

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Introduction
We present a reconstruction framework for pre-clinical proton computed tomography (pCT) and investigate the energy dependence of reconstructed relative (to water) stopping power (RSP) for proton energies relevant for small-animal imaging.

Materials & Methods
Proton radiographies were obtained from FLUKA Monte-Carlo (MC) simulations with 75MeV pencil beams using the beamline model of a clinical proton therapy facility. The in-silico detector model consisted of two gas-based tracking detectors, perpendicular to the beam’s axis, registering position and direction of individual protons before entering and after exiting the phantom and a time-projection-chamber-based range telescope for residual range measurement. Cylindrical phantoms of various tissue-mimicking materials with different radii varying from 5 mm to 20 mm were studied. For each phantom, the RSP image of a central slice with 10mm thickness and 0.2×0.2 mm² pixel size was reconstructed, using 180 projections in 2° increments with 10^6 initial protons per projection scanning along a 4cm field covering the phantom diameter. A total variation superiorization ordered-subset simultaneous algebraic reconstruction technique (TVS-OS-SART) algorithm was implemented in C++. Proton trajectories within the phantom were estimated using straight-line and cubic-spline path models.

Results
Implementation of pCT reconstruction in C++ considerably reduced computation time by a factor of 3 compared to our previous MATLAB-based reconstruction. Mean reconstructed RSP showed minor difference below 0.3 % relative to ground truth for all studied materials. A comparison of different cylinder radii has shown that the energy dependence of the RSP is negligible for proton energies relevant for small-animal imaging. Figure 1 shows results for one of the employed materials.

Summary
We developed a small-animal pCT reconstruction code faster than our previous MATLAB-based implementation. Energy dependence of the RSP at low proton energies has shown no substantial impact on the imaging performance. Supported by ERC.

Appendix

Figure 1: Mean reconstructed RSP of liver cylinders with varying radius.
**Introduction**
Radiotherapy with dose rates above 40 Gy/s ("FLASH") could reduce side effects in healthy tissue and increase the therapeutic window. Cyclotrons, however, must be operated at the highest energy to provide the necessary dose rate. A 3D range-modulator (RM), optimized for single energy and individual tumour shape, may present optimal solution for FLASH.

The range of the highest energy (about 38 cm at 250 MeV) must be adjusted to the tumour depth using a suitable absorber. This work uses Monte Carlo (MC) simulations to investigate the effect of absorber in combination with 250 MeV protons on the dose distribution behind a 3D-RM compared to a reference simulation with 151 MeV without absorber.

**Materials & Methods**
The dose distribution of a 3D-RM, previously optimized for 151 MeV protons and a complex tumour shape, was simulated in a water phantom (MC FLUKA). Two modifications were then performed: the energy was increased to 250 MeV and an approximately 19 cm thick PMMA absorber was positioned immediately behind the RM and in front of the water phantom.

In the subsequent simulation the dose from each scan-spot was scored individually, then assigned a weighting factor and optimized for a homogeneous dose in the target volume to account for the change in energy and scattering. The final simulation was performed with the optimized scan-spots.

**Results**
There is good agreement between both dose distributions, 151 MeV without absorber and 250 MeV with absorber. The dose in the target volume shows a high degree of homogeneity and conformity.

**Summary**
The 3D-RM is a promising method to achieve very fast treatment with a high degree of dose conformity and homogeneity in proton therapy with one energy. A 3D-RM in combination with a high proton energy and the appropriate absorber could enable FLASH irradiation in the future.
Joint Conference of the ÖGMP, DGMP and SGSMP

eP64 In-house developed set-up of a TLD-based in-vivo dosimetry system for intraoperative electron beam radiotherapy (IOERT)

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Introduction
This study reports on the set-up and the usability of thermoluminescent dosimeters (TLD-100) based in-vivo dosimetry for IOERT treatments of pancreatic cancer. It presents an in-house developed setup enabling the placement of multiple TLDs within a layer of flap material, flexible to be placed directly over the target region and be fixated under the applicator’s end.

Materials & Methods
LiF:Mg,Ti (TLD-100) dosimeters are calibrated for 10 Gy. Their response is determined for different electron energies and a wide dose range (4Gy to 22 Gy). The need for a correction factor is investigated for different experimental setups of TLDs in water-equivalent flap material, IOERT plastic applicators and solid water phantoms. Irradiations were conducted with conventional linac and mobile accelerator. PDD curves with and without the flap material are compared in a Gamma Analysis (2 %, 2 mm). EBT3 radiochromic films are used to investigate the 2D dose distribution in different depths below the flap. A TLD loading system to be used in OR has been developed and implemented in this experimental study (figure 1).

Results
TLD-100 dosimeters show independence on the electron beam energy. A non-linear response is observed for doses above 18Gy. The flap material does not cause perturbations on the electron beam field. Film measurements in different depths behind the flaps show a corresponding pattern of the flap material. However, the effect is negligible at the depth of dose maximum. TLDs inside the flap and reference measurements agree within 1.14 %.

Summary
Our results demonstrate that TLD-100 can be used for in-vivo dose verification in IOERT if correction factors for non-linear response are taken into account for doses above 18Gy. The in-house developed flap setup has no significant influence on the TLDs’ dose accuracy and has proven to be suitable for in-vivo dosimetry purposes in the OR environment.

Appendix 1

Figure 1: In-house developed in vivo dose measurement set up
eP65 Monte Carlo simulations of correction factors for a parallel-plate chamber in VHEE beams

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Introduction
Therapeutic irradiation of tumor tissues with ultra-high dose rates (UHDR) is one of the most promising innovations in modern teletherapy. Many studies demonstrated improved tolerance of organs-at-risks irradiated at UHDR compared to conventional radiotherapy. A possible technical implementation of UHDR irradiation is to use Very High Energy Electron (VHEE) beams. Measurements under these conditions using ionization chambers are still very challenging due to the possible large corrections required for recombination effect on the one hand; and the lack of other correction factors for these VHEE beams in standard dosimetry protocols. In this work, the latter have been derived from Monte Carlo simulations for a parallel-plate chamber.

Material & Methods
A prototype parallel-plate chamber (PTW Freiburg) with 1 mm electrode distance and 2.5 mm diameter collecting electrode was investigated. The chamber was modelled using EGSnrc and the user-code egscbamber. The beam-quality correction factors $k_{E,M}$ were simulated between energies 6 and 200 MeV. Furthermore, the depth-dependent cavity perturbation corrections $P_{cav}$ were determined. For comparisons, simulations were also performed for the Advanced Markus chamber (PTW Freiburg).

Results
The $k_{E,M}$ of the prototype chamber lie between 0.96 and 0.80 within the energy range between 6 and 200 MeV. The $P_{cav}$ was found to be depth-dependent but the effect decreases with increasing energy. At low energies, the depth-dependence of $P_{cav}$ can be largely compensated by shifting the chamber along the depth-axis. This shift can be considered as the displacement of the chamber effective point of measurement (EPOM) from its reference point located at the front surface of the air cavity.

Summary
The prototype chamber investigated behaves similarly to established chambers, such as the Advanced Markus chamber. Due to the more rigid design adopted with reduced electrode distance, it is expected to possess more favorable behaviors under UHDR conditions.
Development of a pixelated silicon detector for daily quality assurance in PBS proton therapy with one single device

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Introduction

In order to achieve a high-dose irradiation while sparing normal tissue, small fields with a sharp lateral dose fall off generated by pencil beam scanning or beam shaping apertures are increasingly used in proton therapy. These irradiation methods require the development of small field dosimetry systems for quality assurance.

The working group focuses on knowledge transfer between the field of particle and medical physics by investigating particle counting pixelated semiconductor sensors which are ideally suited to the quality assurance of small fields in proton therapy due to their high spatial resolution.

Materials & Methods

We perform measurements of small proton fields with a hybrid detector consisting of a 2d array of silicon pixels with a size of (250 x 50) $\mu$m\textsuperscript{2} and a FE-I4B readout chip bump bonded to it [1].

To assess their applicability in quality assurance those detectors are used to characterize the lateral beam profiles of different irradiation modes at the WPE Essen. In addition to a 100 MeV single pencil beam spot with an expected sigma of 5.53 mm, the image of the edge of a brass absorber was measured to determine the resolution of the dose gradient.

Results

The measured beam profile of a single pencil beam spot matches the expectations within $\pm$4\%. Further measurements underline the possibility to investigate the dose gradient at the field edge with a spatial resolution of 20 $\mu$m.

Summary

We present the results of first measurements to show the advantages of silicon pixel detectors designed for particle physics in quality assurance of small fields in proton therapy.

References

Development of scatter correction for integration mode proton imaging for a small animal irradiation platform

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Introduction
A novel system for pre-clinical proton therapy studies foresees proton imaging for set-up and accurate treatment planning. In integration mode, imaging at modern synchrocyclotron-based proton therapy centers with high instantaneous particle flux is possible. Commercially available detectors, such as large-area CMOS sensors allow the determination of the object’s water-equivalent thickness (WET). However, image quality is strongly affected by multiple Coulomb scattering. We present experimental results and methods for proton scatter correction.

Materials & Methods
Image contrast is achieved by recording the proton energy deposition in the detector pixels for several incoming beam energies and a signal decomposition method that retrieves the WET. A single planar 114x65 mm² CMOS sensor (49.5μm pixel pitch) behind the imaged object was used. The 65MeV beam at Centre Antoine-Lacassagne (Nice, France) was passively degraded to produce probing energies suitable for small-animal sized objects.

To assess WET accuracy, a micro-CT calibration phantom with 10 inserts of tissue-mimicking materials was imaged (see Figure 1). The phantom-to-detector distance was 0.3, 1.3 and 3.3 cm. Several methods (Monte Carlo-based and analytical) for proton scatter correction were investigated, some using a CBCT image of the phantom as prior knowledge.

Results
The average relative WET error compared to ground truth was <1 % for 0.3 cm spacing and <2 % for 1.3 cm. For the worst case of 3.3 cm distance, preliminary results showed that WET relative error was improved from 30 % to only 3 % using scatter correction. Spatial resolution was better than 0.2 mm, when scatter correction is applied.

Summary
A pixelated CMOS detector and post-processing methods enable proton radiographic imaging for small-animal-sized objects with reasonable WET accuracy and excellent spatial resolution by exploiting prior knowledge.

Supported by ERC.

Appendix

Figure 1: Calibration phantom (left) and integration mode proton radiography without (middle) and with (right) scatter correction.
**Introduction**

Ionoacoustics (IA) is a promising approach for Bragg peak (BP) localization (BPL) currently being investigated in the development of a small animal irradiator. As part of this project, a detector array is to be designed in order to locate the BP inside a mouse. Presented here is a simulation study performed in homogeneous water phantoms where various array designs, based on flat disc sensors, were investigated.

**Materials & Methods**

3D simulations were run using k-Wave where a detector array recorded IA signals from a 50 MeV proton beam degraded from a 70 MeV clinical beam. The BP was localized by iterative time-reversal-reconstruction (TRR) of the initial dose-induced pressure. The dose was thereafter deduced from the reconstructed pressure by accounting for the medium density and Grüneisen parameter. 2D and 3D arc arrangements constituting of various numbers of sensor elements were considered for a proposed detector array. The arc’s eccentricity, its diameter and sensor dimensions were varied in order to minimize BPL error. Prior to the reconstruction, the point-spread-function (PSF) was evaluated to determine the image distortion induced by the array geometry and pulse duration which was then deconvolved from the reconstructed pressure to improve the BPL accuracy.

**Results**

Deconvolving the PSF reduced BPL error, especially for higher proton pulse widths (viz. BPL error reduced by 75% for 10 μs pulse width). 3D arrangements made up of multiple arcs localized the BP to within 1 mm of the actual BP position.

**Summary**

The proposed detector array and reconstruction method allow for sub-millimetric BPL error. Although off-line PSF calculation is time-consuming, it negates the need to run multiple iterations of TRR for accurate BPL and hence reduces on-line reconstruction time. Next steps will involve an *in-silico* real mouse study where the medium properties shall be derived from US/CT images.

**Supported by ERC.**
Session 25 I Dosimetry in Precision Photon Radiotherapy 2

V98 Planverification in Robotic Stereotactic Radiotherapy: Combining a Diode-Array System with Film

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Introduction
Small, non-coplanar, non-isocentric fields in robotic stereotactic radiotherapy require individual plan verification. A point dose measurement is recommended by the manufacturer whereas Report TG 135 [1] advises the use of film. It was shown that a diode array phantom can be used as two-dimensional means of patient plan verification [2]. In this study, a modified Delta4-Phantom combining diode-array measurement and film is investigated with regard to feasibility and advantages in terms of better patient plan verification.

Materials & Methods
Plans with PTVs ranging from 51.1 to 108.3 cm³ were studied using the Delta4-System with two orthogonal silicon-diode arrays. By a cutout in the cylindrical phantom a so-called ball-cube-phantom loaded with end-to-end (E2E) test-films was inserted prior to irradiation. After dose calibration and masking of the notches in the E2E-films using an in-house Matlab-script, the measured film dose was compared to the planned dose, shown in Fig1. The diode-array-dose was examined using the Delta4-software.

Results
13 out of 14 evaluated films are in accordance (gamma pass rate > 95 % with DTA 1 mm and dose difference 3 %) with the planned dose. For repeated measurements, the dose difference criterion for film-film comparison had to be increased to 4 %. The results of the diode array measurements were acceptable for 5 out of 7 irradiated fractions (1mm/3 %; see Tab1).

Summary
The feasibility of simultaneous use of films and diode array measurement was shown. Further investigations are necessary to evaluate the reliability of the results. Workflow improvements by the manufacturer could make the tested combination a preferred alternative of plan verification compared to single point measurements.

Appendix

Fig1: a) Film dose b) Planned dose c) Gamma comparison (1mm/3%; blue: masked values)
Tab1: Results of the evaluation of the diode-array-measurements

<table>
<thead>
<tr>
<th>Plan</th>
<th>Gamma '1 mm/3%' Pass Rate, Delta4-Software (10% dose threshold) [%]</th>
<th>Median Dose Deviation [%]</th>
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<tbody>
<tr>
<td></td>
<td>1. Irrad.</td>
<td>2. Irrad.</td>
</tr>
<tr>
<td>Patient 1</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Patient 2</td>
<td>78.6</td>
<td>79.3</td>
</tr>
<tr>
<td>Patient 3</td>
<td>97.4</td>
<td>96.7</td>
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</table>

References


V99 Evaluation of a new inverse planning software and implementation of a plan verification method for gamma knife treatments

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Introduction
Gamma Knife is a stereotactic radiosurgery instrument with Cobalt-60 radiation sources for the treatment of several brain disorders. Although treatment planning systems in Gamma Knife radiosurgery offer internal optimisation tools, the conventional technique is still forward planning. Such inverse planning software often converges to the local minima of the objective function precluding the optimal solution. The software IntuitivePlan (IP) uses a new global convex optimisation algorithm. Based on dose constraints in the target region and critical organs, inverse planning should optimise the conformity and selectivity while minimising harm to organs at risk.

Another thematic focus in collaboration with the Gamma Knife Centre in Bochum includes plan verification. When creating complex plans, a dose verification is recommended for Gamma Knife therapy as it is required in teletherapy.

Materials & Methods
In a prospective user study with 100 patients, IP was tested in clinical practice. Plan quality metrics, e.g. the coverage, the selectivity, the efficiency index (EI) and Paddick's conformity index (PCI), were evaluated by contrast with conventional expert plans.

To ensure submillimetre dose accuracy for future treatments, standardised plan verification with a new phantom based on film dosimetry has been implemented. The gamma analysis is used to evaluate the conformance between the calculated and measured dose distributions.

Results
For different available IP planning strategies and various disorders, both a significant improvement in selectivity and PCI were achieved. The reduction in planning time and higher EI were assessed for the following planning strategies: Maximum coverage in favour of selectivity and maximum selectivity. However, there were no advantages for certain brain disorders or planning strategies.

Summary
In radiosurgery planning, especially for complex target volumes, IntuitivePlan achieved better selectivity while maintaining good coverage. Prospectively, benign brain tumours can be treated more efficiently.

The suitability and feasibility of plan verification are also presented.
Dosimetric comparison between HyperArc (HA) and conventional VMAT for single and multiple brain metastases with monoisocentric technique: a single institution experience.

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Introduction
Stereotactic radiosurgery (SRS) for single and multiple brain metastases has become nowadays widely used, demanding for accurate and fast treatment. Several linac based mono-isocentric techniques have been developed to facilitate the implementation of such treatments in daily clinical practice. The aim of this study is to evaluate and compare dosimetric differences between an automated planning system (HyperArc HA) and a conventional VMAT approach (Pinnacle P3).

Materials & Methods
For 10 patients with brain metastasis (1-10 lesions) plans have been retrospectively calculated with both techniques in a mono-isocentric approach with 4 non coplanar arcs (couch 0°, +45°, +90°) and same collimator geometry. The prescription doses range between 21-27Gy in 3 fractions and 20-30Gy in 5 fractions, and have been adapted to match target coverage. The HA plans have been optimized on Eclipse but the final dose has been recalculated on Pinnacle with a 0.125 cm dose grid step, which reduces possible differences in dose calculation accuracy especially in inhomogeneous tissue. The plan quality has been assessed using the following metrics: gradient index (GI), selectivity, Paddick (PCI) index, D2% (PTV), D98% (PTV), Dmean for the target, V(4-8-12-18) Gy for brain-GTV, MU and time to plan.

Results
PCI slightly improved on average for HA plans as well as GI and selectivity, especially for HA multimetastatic plans, while single metastasis plans show almost comparable results. For HA plans, V18 to the brain-GTV is always smaller (20 % on average) than for the corresponding P3 plans as well as V12 (15 % on average). Lower doses of V8 and V4 show very slightly differences if any. No differences result in the metrics concerning the coverage of PTV. Total number of MU is systematically higher for HA plans (25 % on average) independently of the number of lesions. When considering the time needed to plan, it is reduced with HA planning (on average halved) compared to conventional VMAT plan.

Summary
This study shows that HA plans achieve similar or slighter better results for the analyzed metrics compared to conventional VMAT plans, while having a higher delivered MU. The time needed to the planner to optimize a plan halves for HA compared to VMAT plans, thus improving efficiency in the SRS workflow especially for multimetastatic treatments.
V101 Investigation of GAFchromic™ EBT3 and EBT-XD films for SRS patient specific pre-treatment QA

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Introduction
The GAFchromic™ EBT-XD films were investigated to determine possible advantages over the EBT3 films regarding dose-response sensitivity, results of patient specific pre-treatment quality assurance (QA) and film non-uniformity for stereotactic radiosurgery (SRS).

Materials & Methods
The dose-response was determined by evaluating the correlation between the scanner pixel values and the irradiated dose. 3 patient specific pre-treatment QA plans with a prescribed dose of 1 x 25 Gy were evaluated for both film types. The local and regional dose fluctuations essentially resulting from the intrinsic film non-uniformity were investigated separately for both film types. Several filters were tested to mitigate the local fluctuations. The mitigation of the regional dose fluctuations by applying triple channel calibration was quantified.

Results
The more appropriate dose-response of the EBT-XD films above 10 Gy led to more accurate measured dose profiles for the 3 patient specific pre-treatment QA plans as shown in figure 1. The gamma passing rates (3 % global, 1mm) were superior for the EBT-XD (96.5 %, 98.2 %, 100 %) than for the EBT3 films (94.6 %, 92.8 %, 94.8 %). Local dose fluctuations between 2.4 % and 3 % were observed for both film types and can be ideally further reduced with a Gaussian filter of standard deviation of 1.0 without losing important spatial information. The triple channel calibration enabled to reduce the regional fluctuations up to a factor 3. The remaining maximum regional dose fluctuation was up to 1.9 % for an EBT3 film and 3.9 % for an EBT-XD film.

Summary
The EBT-XD films are superior to the EBT3 films for SRS patient specific pre-treatment QA. Substantial regional dose fluctuation due to the intrinsic film non-uniformity are remaining even after applying triple channel calibration.

Appendix 1

Figure 1: Comparison of calculated (green) and measured dose profile with EBT3 (blue) and EBT-XD (orange) films for a patient specific pre-treatment QA plan.
Monte Carlo calculation of magnetic field correction factors for ionization chambers

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Introduction
Integrating medical linear accelerators and Magnetic Resonance Tomography (MRI) allows monitoring the moving tumor during radiotherapy treatment. Due to the Lorentz force, the magnetic field impacts the trajectories of the secondary electrons affecting both the dose distribution and the dose response of a detector. Therefore, new correction factors are required in clinical dosimetry on MR-linacs. In this work, the Monte Carlo code EGSnrc was applied to calculate the correction factors $k_B$ of two ionization chambers (SNC 125c and SNC 600c, Sun Nuclear Corp., Melbourne, USA) for different strengths and directions of the magnetic field $B$.

Materials & Methods
The chambers were modeled in detail according to the information given by the manufacturer and placed in a water phantom (30x30x30 cm³). They were irradiated under reference conditions according to the IAEA TRS-398 and DIN 6800-2 codes of practice. A 6 MV spectrum of an ELEKTA linac was used as photon source. The magnetic field was oriented in different directions relative to the beam axis and the chamber’s symmetry axis and was varied between 0 and 2T in steps of 0.2T.

Results
In the case where the magnetic field is parallel to the chamber axis, $k_B$ of the SNC 600c and the SNC 125c changes in dependence of the magnetic field strength $B_x$ up to 1 % and 0.5 % respectively; if the magnetic field is perpendicular to the chamber axis ($B_y$), the change is up to 7 % and 2.3 % respectively. The variation of $k_B$ as a function of $B$ is somewhat larger applying the TRS-398 protocol than applying the German DIN protocol.

Summary
In this study, the $k_B$ values for two different protocols TRS-398 and DIN6800-2 in different magnetic field strengths were determined.

Appendix1

**Fig 1**: Correction factor $k_B$ as a function of the magnetic field $B$ for the ion chamber SNC 600c.
Monte Carlo calculations of the beam quality correction factor

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3Sun Nuclear Corporation, Melbourne, FL, United States
4Marburg Ion-Beam Therapy Center (MIT), Marburg, Germany

Purpose
Although several studies provide data for reference dosimetry, ionization chambers are in clinical use worldwide for which no beam quality correction factors $k_Q$ are available. The goal of this study was to calculate beam quality correction factors $k_Q$ for reference dosimetry according to dosimetry protocols TG-51, TRS 398 and DIN 6800-2 for the farmer type ionization chamber SNC600c and the small volume ionization chamber SNC125c, both Sun Nuclear Corporation (Melbourne, FL).

Methods
Monte Carlo simulations using EGSnrc have been performed to calculate the absorbed dose to water and active air volume of ionization chamber models. Both spectra and simulations of beam transport through linear accelerator head models were used as radiation sources for the Monte Carlo calculations.

Results
$k_Q$ values as a function of the respective beam quality specifier $Q$ were fitted against recommended equations for photon beam dosimetry in the range of 4 MV to 25 MV. The fitting curves through the calculated values showed a root mean square deviation between 0.0010 and 0.0017.

Conclusion
The investigated ionization chamber models are not included in abovementioned dosimetry protocols, but are in clinical use worldwide. This study covered this knowledge gap and compared the calculated results with published $k_Q$ values for similar ionization chambers. Agreements with published data were observed in the 95 % confidence interval, confirming the use of data for similar ionization chambers, when there are no $k_Q$ values available for a certain ionization chamber.
Introduction
Dose measurement using an air-filled ionization chamber is subject to the displacement effect that can be corrected by placing the chamber’s effective point of measurement (EPOM), which is normally shifted towards the source, at the depth of measurement. In the presence of a magnetic field, the angular distribution of secondary electrons is altered from the magnetic field-free case resulting in a different EPOM.

Materials & Methods
The EPOM of three ionization chambers (Farmer 30013, Semiflex 3D 31021 and PinPoint 3D 31022, all from PTW Freiburg) in a magnetic field up to 1.5 T has been determined by performing Monte Carlo simulations for different geometrical configurations by varying the orientations of the magnetic field and the chamber axis using a 6 MV and a 10 x 10 cm² photon beam. Thereby, the point of entrance (PoE) of each electron at the cavity boundary along with its energy deposited (EDEP) within the sensitive volume were scored. The shifts of PoE from the chamber reference point, weighted by the EDEP, were used to calculate the magnetic field dependent EPOM shift in three spatial directions ($\Delta x$, $\Delta y$ and $\Delta z$). Additionally, the $\Delta z$-shifts were obtained by minimizing the deviation of dose-to-water and dose-to-air ratios from simulated depth dose curves.

Results
In the magnetic field-free case, the $\Delta z$-shift ranges from -0.34r to -0.48r, while its magnitude is reduced by up to 50% in a 1.5 T magnetic field. The results from both methods show comparable magnetic field dependence of the $\Delta z$-shift. Additionally, the $\Delta y$-shift opposing the preferential direction of the Lorentz force increases with magnetic field, e. g., for the radially positioned Farmer chamber up to 0.26r at 1.5 T magnetic field.

Summary
The method proposed allows for the determination of chamber EPOM shifts in three spatial directions. The results show that chamber positioning must be adjusted in a magnetic field.
Experimental validation of time-resolved estimated synthetic CTs at 3.65 Hz for MR-guided lung tumor treatments

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Introduction
We propose a method to create continuous time-resolved estimated synthetic CTs (tresCTs) based on orthogonal cine-MRI for MR-Linac treatments of moving lung tumors.

Materials & Methods
The method was tested with a porcine lung phantom that reproducibly simulates respiratory-induced target motion with gelatin nodules as surrogate lesions. A mid-exhale 3DCT and ground truth (GT) 4DCT were acquired. The phantom was subsequently transported to a 0.35T MR-Linac. A mid-exhale 3DMRI and interleaved orthogonal (sagittal/coronal) cine-MRI, intersecting the moving lesions, were acquired at 7.3Hz. The 3DCT, 3DMRI and orthogonal cine-MRI served as input data for an extended motion model [1] to create 82s-long tresCTs at 3.65Hz (Fig.1). Ten tresCTs were generated for ten targets in two lung specimens and three motion patterns. Step-and-shoot IMRT plans (8 × 7.5Gy) were created on the mid-exhale GT-4DCT image. The tracked lesion, expanded by a 5mm PTV margin, was used as target. Each plan was recalculated on one randomly sampled tresCT image per breathing phase and all GT-4DCT phases. Phase-dependent DVH parameter and dose differences were quantified.

Results
The range of nodule motion amplitudes was 3-16mm. The median absolute differences of D98%, D50% and D2% were 2.1 %, 0.8 % and 0.5 % for the PTV (100 DVH comparisons). The median pass rate of the dose difference analyses (2 % prescription dose acceptance level; 10 % dose threshold) was 97.4 %. Breathing phase-dependent lung density variations led to phase-dependent dose deviations in the vicinity of the GTVs (Fig.2).

Summary
The method provided accurate tresCTs at high temporal resolution. Dose differences between GT and tresCTs were at clinically acceptable levels. The tresCTs could be used for dose accumulations to guide intra- and interfractional treatment adaptations.

Acknowledgements: DFG

References
Fig. 1: Workflow of the proposed method.

Fig. 2: Exemplary GT, tresCT, their difference and corresponding dose distributions (PTV shown in red).
Joint Conference of the ÖGMP, DGMP and SGSMP

V106 Intrafractional prostate motion analysis during MR-guided radiotherapy

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2German Cancer Consortium (DKTK), Partner Site Munich, Munich, Germany
3LMU Munich, Medical Physics, Munich, Germany

Introduction
Combined MR-linacs provide non-invasive real-time tracking of the tumour motion using 2D cine-MRI during treatment delivery. This study aimed at evaluating the prostate motion captured during MR-guided radiotherapy.

Materials & Methods
Cine-MRI videos (mpeg format) were acquired during each fraction of free-breathing MR-guided online adaptive radiotherapy for 10 prostate cancer patients at a 0.35T MR-linac (ViewRay-MRIdian). The GTV was used as tracking target and expanded isotropically by 3mm to create the gating window. During treatment, the target was continuously deformed by the vendor’s optical flow algorithm. Using the videos and an in-house algorithm, the center-of-mass coordinates of the tracking structure were calculated relative to the static gating window in anterior-posterior (AP) and superior-inferior (SI) direction.

Results
Prostate motion was evaluated for 174 fractions totaling 24.2 hours (Fig 1). Over all patients, the average [2.5th, 97.5th] percentile tumor motion was [-3.8 mm, 2.8 mm] in AP and [-2.8 mm, 3.8 mm] in SI direction (Fig 2). The motion amplitude varied considerably from fraction to fraction, and between patients. For the patient with the most pronounced motion, prostate-shifts by more than 5mm were found 13.5 % of the time (mean value over all patients: 4.7 %).

Summary
Real-time cine-MRI over multiple treatment fractions and patients showed that prostate motions magnitudes of up to ±4mm frequently occur during MR-guided treatment. The obtained motion data can be used for estimating treatment efficacy in different margin/gating window scenarios, as well as for estimating the dosimetric impact of the residual prostate motion.

Fig 1: (left) Target motion in AP and SI direction for an exemplary patient’s single fraction and (right) the probability-of-presence of target during the fraction. The gating boundary is shown in red.
Fig 2: Violin plots of the prostate motion in AP- and SI-directions over all fractions for each patient. Shifts beyond 10mm are not shown.
Joint Conference of the ÖGMP, DGMP and SGSMP

V107 Delta radiomics analysis through machine learning for patients treated for liver metastases at a hybrid MR-LINAC

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Introduction
MR guided radiotherapy offers a unique opportunity to track the patient response over the course of therapy. Previous work investigated the predictive value of radiomics features at a given time point. In this study, we investigate the evolution of the features (delta radiomics) for liver metastases and healthy liver tissue over the treatment sessions.

Materials & Methods
The MR images of N = 30 patients were acquired with a 0.35 T scanner during online adaptive fractionated SBRT. Additionally to the daily re-contoured GTV, we defined structures including healthy liver tissue at different distances (Fig. 1) and two control structures in the healthy liver inside and outside the field (not shown). The data was processed with an in-house developed radiomics software. In the post-processing, the machine learning package scikit-learn was used to classify the features depending on their evolution and select the ones providing information independent from the GTV volume changes. The patients were also classified.

Results
Clusters of GTV features with Pearson correlation $r \leq 0.4$ to the GTV volume change were identified (Fig. 2), demonstrating that additional and independent information can be extracted from a radiomics analysis. The control structures demonstrated the stability of the features outside the radiation field (not shown). The patients were classified in sub-groups depending on the longitudinal evolution of the features calculated on the GTV or on the healthy liver (Fig. 3).

Summary
We presented a method to reduce the dimensionality of the radiomics features. We demonstrated that robust additional information independent from the GTV volume changes can be extracted through a radiomics analysis for patients treated at a ViewRay MRIdian. Future work will include the study of the correlation between longitudinal feature evolution, applied dose and follow-up parameters.

Figures

Fig. 1: Analyzed structures
Fig. 2: Example GTV features classification
Fig. 3: Example patients classification
Monte Carlo beam modelling considerations towards magnetic resonance guided particle therapy.

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\textsuperscript{3}University of Wollongong, Centre for Medical Radiation Physics, Wollongong, Australia
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Introduction
Monte Carlo (MC) beam models represent a powerful tool to support dose calculations towards magnetic resonance guided particle therapy (MRgPT). In this study, two dedicated beam models for protons and Carbon ions were developed and benchmarked against experimental measurements to be used for MRgPT treatment planning (TP).

Materials & Methods
The GATE9.0/Geant4 MC beam models were experimentally validated for protons and \textsuperscript{12}C ion beams at different clinical energies, covering effective ranges in water from 3-30 cm at the MedAustron ion therapy center. A dipole magnet (Danfysik, Taastrup, Sweden) (B=0-1T) positioned at the treatment isocenter was used to mimic the magnetic fields expected in future MRgPT systems. Simulations included the clinical nozzle as well as both the homogenous and fringe fields maps, previously calculated using the COMSOL software. In-depth and lateral dose profiles were measured in a water phantom (810×125×400 mm\textsuperscript{3}) to benchmark the MC beam model at 0 and 1T. Additional beam optics measurements in air were conducted using a Lynx detector (IBA, Schwarzenbruck, Germany) and EBT3 films at different distances to the IC and magnetic field strengths.

Results
Range differences lower than 0.7 \% were obtained between simulated and measured IRPDs for all energies and magnetic fields, see Fig.1. Simulated in-air lateral beam deflection were found to be within 12 \% with respect to experimental measurements, see Fig.2. At the isocenter, beam deflections are expected to agree within 0.5 mm for all configurations.

Summary
MC beam models, allowing to generate basic beam data for clinical particle beams in magnetic fields up to 1T, were successfully validated against experimental measurements. Further benchmarking against more complex irradiation fields is foreseen.
Appendix 1

Figure 1: In-depth dose distributions of 12C beams in water at B=1T.

Appendix 2

Figure 2: In-air trajectories of a 12C beam. The inner subplot shows zoomed the isocenter region.
V109 Quantitative sodium MRI of the renal cortex and medulla at 7T

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Introduction
Non-invasive quantification of the sodium concentration in vivo offers a unique tool for functional 3D investigation of renal physiology. Thus, the aim of the presented work was to improve the quantification of the tissue sodium concentration (TSC) in the human kidneys via 23Na-MRI.

Materials & Methods
The at 7T acquired 23Na-MR data was corrected for respiratory motion[1], T1 relaxation effects (in four external reference vials and the phantom), as well as for transmit (B1+) and receive (B1-) field inhomogeneities. Phantom measurements were conducted to evaluate the effectiveness of the utilized corrections before applying the workflow to in-vivo data (2 healthy volunteers). Additionally, high-resolution 1H-images were acquired at 1.5T and used for segmentation of cortex and medullae followed by a rigid registration onto the 23Na data (Fig. 1).

Results
After all corrections, the mean TSC of two volunteers within the entire kidneys, the cortices and medullae were determined (Fig. 3, Tab. 1).

Summary
A combination of a 23Na concentration calibration with external reference vials and simulated receive field corrections adapted for the specific setup was performed for the first time at 7T. Retrospectively sorted sodium B1+ maps are feasible and the applied corrections improved the quantitative measurements in phantoms. The correction methods were subsequently applied to in-vivo data and these TSC values agree well with literature values measured at 3T[4].
Figure 1: Registration and segmentation, volunteer one.

Figure 2: Phantom measurements.
Figure 3: Abdominal $^{23}$Na-MRI of volunteer one (Density-Adapted 3DPR sequence$^{[2]}$ with Golden-Angle acquisition$^{[3]}$, image: $T_E=1.00\text{ms}, T_R=150\text{ms}, \alpha=61^\circ, T_{acq}=40\text{min 45s}$, $B_1^+$ maps: $T_E=1.55\text{ms}, T_R=150\text{ms}, \alpha=45^\circ/90^\circ, T_{acq}=20\text{min 30s each}$).

<table>
<thead>
<tr>
<th>Volunteer No.</th>
<th>Side</th>
<th>Respiratory State</th>
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<th>Cortex [mM]</th>
<th>Medulla [mM]</th>
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<tr>
<td>1</td>
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<td>49.8± 5.9</td>
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<td>1</td>
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<td>96.0±18.8</td>
<td>50.3± 5.2</td>
<td>100.4±4.9</td>
</tr>
<tr>
<td>1</td>
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<td>105.3±25.4</td>
<td>50.9± 7.3</td>
<td>100.2±6.4</td>
</tr>
<tr>
<td>1</td>
<td>right</td>
<td>whole</td>
<td>93.9±19.6</td>
<td>66.3± 6.4</td>
<td>98.7±3.9</td>
</tr>
<tr>
<td>1</td>
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<td>93.5±19.1</td>
<td>59.5± 4.9</td>
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<td>1</td>
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<td>66.5±12.7</td>
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<td>73.2±10.9</td>
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<td>90.8±4.0</td>
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<td>2</td>
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<td>78.2±15.0</td>
<td>54.1± 3.4</td>
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</tr>
<tr>
<td>2</td>
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<td>82.6±14.1</td>
<td>59.6± 5.0</td>
<td>78.9±2.0</td>
</tr>
<tr>
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<td>84.6±16.1</td>
<td>56.9± 6.1</td>
<td>73.0±1.7</td>
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<td>79.0±16.9</td>
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</table>

Table 1: Determined in-vivo TSC.
References
Session 27 I Radiation Protection, Quality Assurance and Risk Management in Radiation Oncology

V110 Linac QA using a 2-D array and spreadsheets

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Introduction
Our aim was to replace film-based Linac QA for six mechanical and dosimetry tests with a fast and simple technique using a low-resolution 2-D ionization chamber array to allow for reproducible and quantitative presentation of results. Here, the method and its validation is presented.

Materials & Methods
A 2-D ionization chamber array (MatriXX Evolution) has been deployed to perform the following DIN 6847-5 and 6875-4 based tests (Figure 1): (A & B) Junction tests, (C) Transmission, (D) Dependence of photon and electron profiles on gantry angle, (E) Stability of photon profiles at small doses, (F) Energy stability at small doses. Spreadsheet templates have been created to import array measurements and to analyse results.

To validate the junction test method and to check its sensitivity, leaf-positioning errors of 0.2 to 2.0 mm were introduced and the results were compared to measurements with radiographic films (both quantitative and pass/fail analysis) and EPID, and to TPS calculations (RayStation). To test its robustness against detector misalignment, the array was shifted in leaf-direction in 2-mm steps to repeat measurements with leaf-positioning errors as described above.

Results
All six mechanical and dosimetry tests can be successfully performed with a 2-D array. In the junction tests, a leaf positioning error of 0.2 mm causes an array response change of approximately 1.0 % in inplane. The array response is linear with the leaf gap/overlap, matches the results of alternative QA tools, and corresponds to the TPS calculations (Figure 2a). An array misalignment of up to 4 mm does not affect the test sensitivity significantly (Figure 2b).

Summary
QA procedures deploying a 2-D array and spreadsheet evaluation have been defined and implemented. The sensitivity of the method and its robustness against misalignment were tested: Sub-millimetre leaf position errors could be detected; the sensitivity was found sufficient and comparable to other tools. The method is robust against detector misalignment of up to several millimetres.

Appendix 1

Figure 1: MLC test patterns for six mechanical and dosimetry test.
Appendix 2

Figure 2: Sensitivity of junction tests (a) and effect of detector positioning (b).
V111 Constancy checks for verifying electron beam properties of an IORT linac: two years' experience with a commercial ionisation chamber array

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Introduction
Constancy checks for IOERT linacs are desirable to verify beam properties, following repairs or modification. Commercial 2D ionisation chamber arrays can be employed to perform these checks to verify flatness, symmetry and electron beam energy.

Materials & Methods
An air filled OD1500 array (PTW-Freiburg) was employed. An in-house PMMA jig attaches the array to a 100 mm diameter applicator, and hence the Mobetron (IntraOp) linac. Perpendicularly incident beams were measured to check flatness and symmetry. In-house polystyrol wedges (15\textdegree, 30\textdegree, 45\textdegree) were manufactured to attenuate the fluence across the clinical electron beam (E6, E9 and E12), resulting in an energy dependent response: reference profiles were measured directly after water-phantom measurements. The constancy of beam profiles (flat and wedged) was verified over a two year cycle of periodic maintenance, repairs and upgrades. Analyses were performed with the array software (Verisoft 8) using DoN and gamma criteria 3\%/3 mm (local).

Fig.1 OD1500 array attached to metal applicator via PMMA jig: 45\textdegree polystyrol wedge inserted.
Results

Fig.2 (a) Comparison of E9 profiles with 15° wedge (W15): orange, blue (reference). (b) Reference energy profiles using W15

![Graph showing comparison of E9 profiles with 15° wedge (W15)](image)

(b)
Gamma passing rates were greater than 95% for all energies over the two year period.

Summary

The W15 has been shown to be suitable to adequately distinguish all clinical electron energies. All gamma passing rates were greater than 95%. The array can detect set-up errors (e.g. lateral shifts in wedge position). Geometrical accuracy of measurements repeated over the two year period is approximately 2mm. The method described enables constancy checks to be performed within 30 minutes, with minimal setup time. However, such array-based constancy checks are no substitute for half-yearly measurements (profile and PDD) in water.
V112 A large area GEMPix detector with a pixelated TFT-based charge readout

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Introduction
Radiation therapy with protons and carbon ions allows for a better conformity of the dose to the tumour and in numerous cases offers significant improvements with respect to conventional radiotherapy. This requires a very accurate dose planning, which has in turn to be guaranteed by appropriate quality assurance procedures with fast and reliable detectors with high spatial resolution. We propose a novel Large-area GEMPix detector, a promising instrument to improve treatment plan verification.

Materials & Methods
The LaGEMPix combines a triple-GEM detector and a thin film transistor (TFT) matrix readout produced by Holst Centre/TNO. The first LaGEMPix prototype uses an optical readout, which consists of a matrix of organic photodiodes (OPD) coated on a TFT readout. This detector is capable of measuring the scintillation light produced by the GEMs. However, the targeted submillimetre spatial resolution was not achieved [1].

We present here an alternative readout, in which the OPD layer has been removed. Now, the secondary electrons produced in the electron avalanche are directly measured by the TFT matrix. The prototype was characterised using low energy X-rays. Measurements with a high-resolution line-pair bar-pattern were performed to determine the spatial resolution.

Results
A first 6x8 cm² prototype of the LaGEMPix with TFT-based charge readout and 126 μm pixel size has been successfully built and tested showing a promising spatial resolution of the order of 1 LP/mm.

Summary
We have shown that this detector with TFT-based readout can measure secondary electrons produced by the GEMs with submillimetre resolution, and hence it represents an important step towards the development of a 20x20 cm² detector to cover the typical maximum clinical radiation field size used in hadron therapy.

Appendix

Figure 1: (a) Lead line-pair mask type 17. (b) Heat map after irradiation with 30 kV X-rays.
References

V113 Installation of a surface guidance system (SGRT) at a heavy ion gantry treatment room – clinical implementation

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Introduction
A surface guidance system (SGRT) has been successfully installed in the gantry treatment room of a heavy ion treatment facility. In this study, we present an analysis of the clinical patient positioning workflow regarding accuracy, robustness and efficiency of the system.

Materials & Methods
The first ten treatment fractions of five test patients (pelvis) were evaluated. Statistical analysis was thus based on 50 fractions. Two scenarios were compared for each of the patients (25 fractions each): (1) The normal image-guided positioning (IGRT) without SGRT using only X-ray imaging. (2) The new workflow with SGRT for positioning.
A crucial aspect for the comparison is the correlation of the X-ray shifts which were acquired in both scenarios. Following parameters were analyzed: translational and rotational shifts of patient position based on the X-ray images as well as time required for the entire positioning process. The objective defined for this study in terms of patient positioning is ± 3 mm (x, y, z) and ± 2° rotation for all three directions.

Results
On average 60 % / 87 % (without/with SGRT) of the analyzed fractions met the target requirement (± 3 mm) in translation and 80 % 94 % in rotation (2 °). Furthermore, the entire time dedicated to patient positioning was reduced by 20 % (1:33min) on average (see Fig. 1) using the SGRT system.

Summary
These results clearly show that SGRT increases the efficiency and the accuracy of the patient positioning process. Furthermore, this analysis ascertains that SGRT meets all requirements for the intended clinical use. Thus, SGRT is a promising precise and reliable tool for patient positioning in such an unique treatment environment.
Appendix 1

*Figure 1: Recorded time of patient positioning and image registration – with and without SGR*