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Detector response in the build-up region of small 6 MV photon fields

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Up to a depth of some centimetres, called build-up region, the dose increases due to indirect ionisation, mainly caused by compton-electrons. Additionally, low-energy photons and electrons, generated in the treatment head and in air, contribute to the dose near the surface. In this non-equilibrium situation, various effects influence detector response, such as volume effect, energy-dependence, detector shape, shielding and materials. In this work we investigated response differences of several detector types (microDiamond, shielded and unshielded diodes, parallel-plate and cylindrical ionization chambers) and possible explanations. Depth dose curves for various field sizes (0.6x06cm^2 - 10x10cm^2) were measured at SSD of 100cm at a Primus accelerator (Siemens, Germany) with a beam quality of 6MV and normalized to the value at 10cm depth. Detector response was compared to EBT3 Gafchromic films (Ashland, USA), which can be assumed to behave nearly water-equivalent. Geometric volume correction factors were calculated from dose maps on the film. From the surface to a depth of 9mm all detectors showed lower response than the film. For example for a 1x1cm^2 field the signal ratio of the detectors to the film was at maximum between 0.9 and 0.97 with the exception of the Roos chamber, for which it was 0.7. Volume averaging could account for the deviations of the largest detectors, but contributed a maximum of 1% to the semiconductor signals. Placing a lead foil below the collimator to filter electron contamination reduced the microdiamond response by 4% in the build-up region. The signal of the unshielded diode was reduced by 5%, twice as much as for the shielded one. In conclusion, we found out that all commercial detectors underestimate the dose near the surface. Electron contamination and volume averaging could explain the observed response differences only partly. The study of further influence parameters is in progress.

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Evaluation of the ArcCheck 3DVH-module

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Before patients are treated with volumetric arc or intensity modulated radiation therapy (VMAT, IMRT) treatment plans have to be verified to ensure that planned and delivered dose distributions concur. Since the prescription is based on dose volume histograms (DVH), it seems reasonable to base decisions on these data. There are commercial systems that reconstruct DVH using different approaches, e.g. the ArcCHECK 3DVH-module (Sun Nuclear) with its planned-dose-perturbation algorithm. We evaluated its performance with regular and artificial treatment plans using Pinnacle (Philips) and a Synergy linac with an Agility MLC (Elekta). The dose at the isocenter was measured with two ionization chambers having different volumes and a MicroDiamond and compared to the reconstructed 3DVH-dose in this region. For 2D comparison, EBT3 film pieces were irradiated in a custom-built inset. The influences of different field sizes were studied. For small fields, the reconstructed dose was higher than the measurement by up to 5% (6 MV) and 3.7% (10 MV) for a 2x2 cm² field. For a standard prostate and a head-and-neck VMAT-plans gamma passing rates (GPR) (3DVH-film) were above 91% (6 MV) and 96% (10 MV). A small and spherical target volume was irradiated with different plan types. The GPR (3DVH-film) for plans with 9 and 15 individual beams and a full conformal arc were better than for half rotation plans. Both influences (field size and plan type) were reduced by including the dose measured in the isocenter in the reconstruction. For half rotation GPR (3DVH-film) (3%/3 mm global, threshold=10%) increased from 42% to 88%. We conclude that the 3DVH module is useable for a standard VMAT plans. In general we recommend measuring the isocentric dose and including it in the 3DVH reconstruction. In further research sensitivity and specificity towards induced errors will be determined.

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Dosimetric calibration of an electronic portal imaging device (EPID)

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The use of complex treatment techniques and small-sized photon beams have increased the need for a highly accurate dose delivery and a patient individual dose verification. Due to the high spatial resolution and the broad availability, the interest in using Electronic Portal Imaging Devices (EPID) for dosimetric information has grown. In this work, we determined the parameters for the dosimetric calibration of an EPID and were able to convert portal images to the equivalent water dose deposited in the detector plane at the depth of 1.2cm.
Measurements were performed on an Elekta Synergy linac with a photon energy of 6 MV and an iViewGT^{TM} α-Si flat panel detector mounted on the linac gantry. The detector was operated in the IMRT-Dosimetric-Weighting mode with a modified calibration. By placing a solid water phantom in the irradiation field, an approximately uniform beam can be achieved during calibration. The dependency of the EPID signal to dose, dose rate, field size and phantom thickness was determined with a Semiflex ionization chamber (PTW, V = 0.3 mm^3). The off-axis dose response and ghosting effects were investigated with an ionization chamber array (PTW-729). EPID images of radiation fields with various sizes and phantoms were calibrated and compared to ion chamber array measurements and treatment planning (Pinnacle 9.10) calculations.
In this clinical experiment the dose profiles obtained by the calibrated EPID images showed good agreement with the array measurements and the TPS calculations. Deviations of less than 3% were observed, mainly attributable to the discrepancies to an entirely uniform beam during the gain calibration of the EPID. In further studies this effect will be evaluated and measurements with IMRT fields will be performed to validate the developed calibration.

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Small animal irradiation: verification of the dose distribution in a phantom using thermoluminescent dosimeters

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Purpose: In absence of a dedicated small animal irradiation device we irradiated mice with a stereotactically equipped conventional linac. To test the suitability of the conventional treatment planning system (TPS) we investigated the dose distribution in a self-designed phantom using Thermoluminescent dosimeters (TLD).
Methods: We used *TLD100 rods* with a *Harshaw TLD Reader 5500 (ThermoFisher)* and a *TLD oven (PTW)* for annealing and regeneration. The experiments are performed in a phantom made of polymethylmethacrylate (PMMA), which is 80 mm long with 35 mm diameter and contains three round cylindrical bores with a diameter of 10, resp. 8 mm with balsa wood as lung and PVC as bone equivalent material. In all, 14 TLDs at various positions in the phantom ('lung', 'spine', 'body') are finally used to compare the dose distribution of calculated plans in the TPS Eclipse (Vers. 13.6) with the measured dose. At least 10-fold irradiation is performed at the linear accelerator *TrueBeam STx* with the energy of 6 MV photons and a dose of about 1 Gy. For positioning we used conebeam-CT (as was done for the mice).
Results: The percentage deviation of the determined dose of all points in the mouse phantom at maximum 15 %, in 'lung', in the other positions 3.4 %.
Conclusions: In conclusion, the TLD results so far agreed with an acceptable margin of less than ten percent on average. However, since for 'lung' the deviations suggest further investigations. Therefore, further tests of different lung materials and additional algorithms applied in TPS will follow as well as further calibration steps for TLD will be carried out for reliable and comparable results.

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Influence of CT reconstruction kernels on dose distribution in liver radioembolization using tissue density estimation

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For successful liver radioembolization, the planning of absorbed dose inside normal liver and tumor tissue is crucial. Patient-individual, local 3D dose distribution can be calculated from SPECT/CT or PET/CT images. Thereby, the local tissue density, determined by conversion of CT Hounsfield units, is one important factor to be considered. To analyze the influence of different reconstruction kernel on dose distribution using CT-based tissue density estimation, we calculated dose distributions using the local deposition method and investigated the resulting effects.
CT data of six patients, who underwent diagnostic CT and pre-therapeutic 99mTc-MAA SPECT/CT imaging for radioembolization planning, were retrospectively analyzed. The SPECT/CT data sets for each patient were acquired on a SymbiaT (Siemens Healthcare) and were reconstructed by three different kernels (B08s, B30s, and B60s). For comparison purposes, diagnostic CTs, that were acquired on a LightSpeed VCT (GE Medical Systems) and reconstructed with a standard body kernel similar to B30s, were analyzed.
In an exemplary case, the determined mean liver density was 1.033 g/ml in the diagnostic CT and 1.010 g/ml in B08s, B30s, and B60s data. Mean tumor density was 1.057, 1.030, 1.031, 1.031 g/ml in diagnostic CT, and B08s, B30s, B60s CT. The mean of local relative dose difference $\Delta_{Bx/diagn} = |D_{Bx}-D_{diagn}|/D_{diagn}$ and standard deviation for CTs with B08s, B30s, and B60s kernel was 0.76 ± 4.41 %, 0.85 ± 4.96 %, and 0.91 ± 5.15 % for liver dose and 0.08 ± 0.99 %, 0.09 ± 1.12 %, and 0.12 ± 1.33 % for tumor dose. In all six cases, global mean liver dose differences were smaller than 2 Gy, and mean tumor dose differences were smaller than 3 Gy. These results show that CTs from SPECT/CT scanners can be used as diagnostic CTs for local density estimation in radioembolization dosimetry, independently from the investigated reconstruction kernels.

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Comparison between differing fill factor definitions for two-dimensional detector arrays

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The fill factor characterizes the error detection capability of a 2D detector array regarding beam collimation errors. It is calculated by the quotient of the sensitive area and the geometric cell area associated with a single detector on the array's surface. While Gago-Arias *et al.* (2012) estimated the sensitive detector width of a single detector as the FWHM of its fluence response function $K_M(x)$, we proposed to quantify the sensitive detector width $w(\Delta, d)$ by identifying, across the detector, the range of the lateral coordinate x where a MLC misalignment of Δmm causes a signal change which exceeds a signal threshold d relative to a homogeneously irradiated detector (Stelljes *et al.* 2017). This raised the interest for a numerical comparison between the two differing fill factor definitions.
In this work the fluence response functions of three commercially available detector arrays were measured using the 0.5 mm photon slit beam introduced by Poppinga *et al.* (2015). The measured fluence response functions of three detector arrays from PTW-Freiburg were used to calculate the sensitive detector widths and the fill factors. For the OCTAVIUS729 and OCTAVIUS1500 arrays, supplied with air-filled ionization chambers, the FWHM fill factors were obtained as 0.53 and 0.71 while the collimator monitoring fill factors were 0.59 and 0.84 respectively. For the inner area of the OCTAVIUS1000SRS array, supplied with liquid ionization chambers, the FWHM fill factor was 1.4, and the collimator monitoring fill factor was 1.0. We conclude that the FWHM fill factor characterizes air-filled ionization chamber arrays quite well, but does not yield a plausible fill factor value for the investigated liquid ionization chamber array.

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Design of a precise scintillation dosimetry system for the measuring of microcollimators

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Ocular brachytherapy is a commonly used modality in treatment of eye cancer. In recent years, nearly exclusively eye plaques with a homogenius layer of ruthenium-106 and plaques containing multiple iodine-125-seeds are applied. The
gamma radiation emitted by iodine is advantageous for the treatment of tumours with a thickness of more than 6-7 mm. Unfortunately, its higher range compared to rutheniums beta radiation leads to irradiation of a greater part of healthy tissue. The patented concept of microcollimators makes it possible to generate steep dose gradients and limit the radiated area to the actual tumour. The underlying principle is an alternating alignment of absorbing and transparent lamellae. This layered structure shapes the radiation field of a single seed in the manner of an x-ray collimator. Due to the small size of the utilized structures, a highly precise measuring method is needed. Scintillation dosimetry has shown to be well applicable for eye plaques in general, but the positioning of the detector has to be more accurate for microcollimators. This contribution focuses on the design of a new device for extremely precise scintillation dosimetry, which should later be used to optimize microcollimators and enable their use in clinical therapy.

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Investigation of PEN based plastic scintillator dosimetry for Iridium-192 afterloading source

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For any tumour treatment it is essential to have the knowledge of the dose distribution. This can be achieved by either numerical simulations or by dosimetric measurements. Depending on the measuring situation it can be advantageous to use a water equivalent detector, such as plastic scintillators. These scintillators can be manufactured in different and even very small sizes in order to gain a high spatial resolution. This applies especially to dosimetry and quality assurance of Iridium-192 afterloading sources. The recently evaluated material polyethylene naphthalate (PEN) can be connected without big effort to the fibre optics and the detector system.

Our research group of the co-operation of the TU Dortmund University and the University Hospital Essen investigates the dosimetric characteristics of this material. We focus especially on the energy dependence of PEN by performing numeric simulations. For an existing dosimetric system at an Iridium-192 afterloading source, the luminous efficiency of the detector, the absorption in the light guiding system, the detection probability of the light sensor and the elimination of the Cherenkov light in the light guide are investigated. First results of this research will be presented.