The energy dependent sensitivity of the TLDs was taken into account by corrections based on the respective energy spectrum of the beams. Read-out (Harshaw TLD 5500 reader), calibration and annealing of the TLDs was performed at the CRD.

**Results:** The imaging techniques were grouped in low- and high-dose according to the absorbed dose per exam. All results are shown in Fig. 1. The CBCT at the IBC is included in both graphs to facilitate direct comparison. Generally the OAR doses depended on the imaging modality and the position of the OARs. The doses for volumetric imaging were on average 2.5-130 times higher than for the planar or stereoscopic image pairs. The dose caused by a CBCT scan at the CRD was ~20 times higher than at the IBC as more projections with higher mAs setting were used. The skin dose was higher where the skin was closer to the X-ray tube (CBCT) or at the entrance side of the beam (anterior, sinister for planar kV; posterior for ExacTrac). The highest dose per exam (up to 150 mGy to the skin) originated from the 3 min fluoroscopy.

**Conclusions:** Imaging modalities like planar kV or stereoscopic imaging result in very low doses (~1.6 mGy) to the patient. To assure accurate positioning imaging should be performed on a daily basis. However, when aiming to image a moving target during irradiation, one has to optimize protocols and imaging time, as the induced dose to OARs cannot be neglected.

**PROFFERED PAPERS: PHYSICS 2: SMALL FIELD**

**OC-0063**

**Commissioning CBCT based Monte Carlo treatment planning system for small animal stereotactic irradiation**

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**Purpose/Objective:** Commissioning a cone beam CT (CBCT)-based Monte Carlo treatment planning system for a commercial small animal stereotactic irradiator.

**Materials and Methods:** The BEAM/EGS Monte Carlo code was used to model 225 kV photon beams from a commercial small animal stereotactic irradiator (X-RAD 225Cx, Precision X-Ray, North Branford, CT). The unit was calibrated in accordance with the recommendations of AAPM TG-61. Both in-air and in-water calibrations were performed at a 30.5 cm source-to-surface distance (SSD) using a 40x40 mm² square reference applicator. The output factors for various applicators were measured using various dosimeters (ionization chamber, radiochromic film) and compared with MC simulations. The gamma index method and AAPM TG 53 recommendations were used to benchmark planar radiochromic film measurements against Monte Carlo simulations in both homogenous and heterogeneous mediums. Benchmarks were performed in both homogeneous and heterogeneous media. CBCT calibration curve was created to convert to a CBCT data to density matrix. The CBCT images obtained on the XRAD 225Cx irradiator were converted to a material /density matrix using CBCT calibration curve. The material /density matrix is used as an input to DOSXYZnrc for MC dose computation. The measured and MC computed absolute doses compared for single and multiple beams in both homogenous and heterogeneous mediums for 10 mm field size. The iso-dose distributions were compared using the gamma index method both for single and multiple beams.

**Results:** The in-water and in-air absolute dose measurements demonstrated excellent agreement of 3.42 and 3.45 Gy/min, respectively. MC and measurement agreement of output factors was within 3% for all field sizes. The agreement between simulated and measured absolute dose in CBCT based homogenous medium for single and multiple beams was within 1%. In CBCT based heterogeneous conditions, it was within 1.5%. Gamma map comparisons between MC and measurement with 3% /0.5 mm criteria indicating 98% passing rate for 10 mm field size.

**Conclusions:** The MC dose calculation in CBCT data was validated in a homogenous medium. The comparison between MC and measured dose distributions was quantitatively validated using the gamma index method for 10 mm field size in CBCT data based homogenous medium. A relation was formed between the Monte Carlo dose distributions and irradiation absolute dose rate. Finally Monte Carlo calculated absolute dose and measured absolute dose in heterogeneous medium are in good agreement.

**OC-0064**

**Development and validation of a treatment planning system dedicated to pre-clinical research**

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**Purpose/Objective:** A new field of research in radiotherapy is small animal image-guided precision radiotherapy. In this, radiotherapy procedures are scaled down to the level of structures in small animals, to study treatment strategies which may be translated into human radiotherapy. To enable this, a combination of high-resolution imaging and small field precision irradiation equipment is needed. The irradiations need to be downscaled in energy, from megavolt to kilovolt energies to avoid extensive buildup regions and beam penumbras. To ensure that complex treatments can be delivered, mimicking patient treatments, a versatile treatment planning system tailored to small animal radiotherapy, is needed, which is unavailable currently.

**Materials and Methods:** A treatment planning system for small animal pre-clinical radiotherapy was developed, named Smart-Plan (Small Animal RadioTherapy Planning system). It is capable of planning the irradiation of small specimens such as mice or rats with either multiple coplanar beams or arcs for 225 kV x-rays. This low photon energy mandates careful assignment of the specimen tissues because of the strong dependence of the photon interaction coefficients (photo-electric effect) on the tissue composition. To this end, the micro-CT image from the onboard high-resolution imager is converted into a density and composition map, by calibration and visual inspection of the material map. Smart-Plan handles accurate beam positioning and absolute dose calculation is performed with Monte Carlo simulations based on a detailed model of the complete irradiator, including an accurate model of the focal spot distribution of the primary electron beam hitting the x-ray target. Smart-Plan comprises an interface to transfer treatment parameters to the irradiator. To speed up the calculation multiple simultaneous simulations are performed on a multi-core computer. To validate Smart-Plan planned and measured dose distributions in a multislab heterogeneous phantom were compared.

**Results:**
Fig 1 shows a screenshot of Smart-Plan of the module where CT images of animal specimens are inspected for their electron density, and where a range of tissues is assigned to the very small voxels. The bottom panel shows a Monte Carlo dose distribution in a mouse thorax from 3 stationary photon beams in the range of 1-5 mm field size. The results are presented as dose-to-medium, meaning the photon transport was done in the proper media and doses are expressed in the media as well (an alternative is to express doses in water). The calculation times for a typical treatment plan are about 5 minutes. The dose verification in the heterogeneous phantom revealed good agreement between measured and calculated dose distributions.

Conclusions: A novel radiotherapy treatment planning system for small animals was developed and validated. The system may play an important role in pre-clinical translational studies.

OC-0065
Small field dosimetry in flattening filter free (FFF) beams: comparison of diode, film and scintillation dosimeters
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Purpose/Objective: Flattening filter free (FFF) beams can improve the delivery of radiotherapy treatments by reducing treatment times. The delivery of stereotactic treatments, in particular, can greatly benefit from FFF beams as an alternative to flattened beams. The combination of high dose per fraction combined with patient immobilization can result in long periods of patient discomfort. However, the small treatment fields used in stereotactic treatments and the changes in beam spectrum and scattering conditions that occur with a FFF beam provides challenging conditions for accurate dosimetry. This study aims to assess the performance of a range of dosimeters in an FFF beam with particular attention focused on small field dosimetry. The dosimeters used were: an ionisation chamber; diodes; an air core fibre optic dosimeter (FOD) and EBT2 film.

Materials and Methods: The beam output ratios (OR) for fields as small as 0.5 cm, were measured at depths of 5 cm and 10 cm in water with all detectors. Measurements were performed on the Elekta Synergy and the Varian TrueBeam at a nominal 6 MV. The response of various detectors at small fields was compared between flattened and FFF beams, as well as to measurements on the Varian Novalis which uses a smaller stereotactic flattening filter.

Results: For all linacs, the FOD agreed with the EBT2 film within measurement uncertainty for all field sizes, in both flattened and FFF beams. In the flattened beam, diode detectors showed an overresponse at small fields, as predicted in the literature (Ralston 2012, McKerracher 1999). For the smallest field, the OR measured with a PTW diode was 4.4% higher than that measured with the FOD. For the same irradiation in an FFF beam, however, the expected overresponse was not observed. The PTW diode instead showed an underresponse of 2.0% relative to the FOD.

Conclusions: These results support the conclusion of Scott (2012), derived from Monte Carlo simulation, that density correction factors for specific beam conditions may not be applicable to other beam conditions. Diode correction factors derived on-axis for flattened beams at a particular depth may not be applicable off-axis, for FFF conditions or at other depths.

OC-0066
Detector comparison for small field output factor measurements with flattening filter free photon beams
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Purpose/Objective: Flattening filter free (FFF) photon beams offer various advantages compared to flattened (FF) beams, e.g. a higher dose rate, reduced head scatter and leakage radiation. Forms of applications of FFF-beams are the treatment of tumors with small volumes in a hypofractionated stereotactic setup and the treatment of concave shaped tumors using IMRT or VMAT. For both, an accurate determination of output factors is mandatory. Therefore, influence of filtering on the measurement of output factors was investigated in this study.

Materials and Methods: Several different ionization chambers and solid state detectors were investigated for small field dosimetry. An Elekta Precise Linac (Elekta, Crawley, UK) which is able to produce 6MV and 10MV FF and FFF photon beams was used in this study. The fields were shaped by a BrainLab M3 µMLC (BrainLAB AG, Heimstetten, Germany). The detectors were mounted in a Blue Phantom (IBA dosimetry, Germany) at SSD 95 in 5cm depth. For this study 10 different square fields between 10x10cm² and 0.6x0.6cm² were investigated. All detectors were pre-irradiated with 1000MU. For each field 5 x 100MU were delivered. A Bragg Peak chamber (PTW, Germany) with its entrance window positioned at the water surface was used to verify the Linac output. The measured output factors were corrected for volume averaging effects which were determined in collaboration with the IAEA. Within this collaboration, output factors measured with the CC01 were compared to alanine dosimeters which agreed within 1% for all investigated field sizes. Hence, the measured output factors were normalized to those of the CC01.

Tab. 1. Summary of detectors used for output factor measurements.

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<tr>
<th>Detector Type</th>
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