switch to enable kV-MV mode. An application program was developed which communicates with the various Linac components over a proprietary port. The software coordinates the online kV-MV imaging system tasks: it manages the readout of the kV-detector using the XIS library (Perkin Elmer) and captures the angular gantry position for each projection online. Gain, offset and defect pixel corrections are applied on the acquired raw MV data. MV detector shift is corrected based on measured flexmap data. For the kV contribution, conventional XVI cone-beam projections are acquired. After appropriate greyscale normalization, MV and kV data are then used to reconstruct a 3D-dataset with a CUDA-accelerated FDK algorithm. After conversion into the compatible .SCAN data format, the combined kV-MV reconstruction volume is imported into the XVI system to enable patient positioning based on information provided by the reference volume, e.g. planning CT.

Results: Figure 1 provides a schematic of the system. Duration of the automated workflow is roughly 10 times faster than the workflow without automation, not including additional Linac preparation for kV-MV mode in the latter case. A detailed time comparison of each step is given in Table 1. No error-prone manual entering of Linac settings has to be done anymore. The handling of the procedure is now stable and requires only minimal training.

Figure 1

Conclusions: The kV-MV CBCT acquisition workflow is now almost entirely automatic, based on interaction with all relevant Linac components over a single proprietary port, minimizing human interaction with the system. This is a prerequisite for safe clinical operation. At the moment the procedure only works in research mode. Risk analysis and documentation, which are the basis for clinical operation as an in-house medical device development, are currently in progress.

OC-0061

Validation of three deformable image registration algorithms using the TEST method
P.W.H. Wittendorp1, R.J.H.M. Steenbakkers1, A. van der Schaaf1, J.A. Langendijk1, A.A. van’t Veld1, N.M. Sijtsema1
1University Medical Center Groningen, Department of Radiation Oncology, Groningen, The Netherlands

Purpose/Objective: Deformable image registration (DIR) is an important tool in radiation oncology for contour propagation and for estimating the actual given dose in adaptive radiotherapy (ART). Presently used methods to quantify DIR accuracy provide information about image regions with high contrast (e.g. anatomical landmarks). However, in ART it is important to know the deformation accuracy in the entire irradiated volume. Therefore, we developed the TEST method that quantifies the DIR accuracy both in high and low contrast regions in the image.

The objective of the current study was to assess three frequently used DIR algorithms with regard to the deformation from planning CT (pCT) to repeat CT (rCT) or from pCT to cone-beam CT (CBCT) in patients treated for head and neck cancer.

Materials and Methods: The study population was composed of 10 head and neck cancer patients. For the purpose of this study, we used as well pCT and rCT as pCT and CBCT. The pCT was deformed to the rCT or CBCT, which were acquired in the last week of radiotherapy. Three different DIR-algorithms were compared: the Fast Symmetric Demons (Demons) and the Salient Feature Based Registration (SFBR), both implemented in Pinnacle 9.100 and the B-Spline from the ITK library, implemented in the Elastix toolbox 4.4. For all deformations the TEST parameters were determined. TEST is an abbreviation for: Target registration error, Expansion and Shear strain of the deformation vector field, and Translivity. Anatomically plausible limits have been set for expansion and shear strain. The translivity gives the lower bound of the error of the deformation per voxel.

Results: For the deformations from pCT to rCT, the target registration error showed minor variation between the different algorithms, as shown in Table 1. However, the expansion and shear strain of the DVF showed a larger difference. Where the Demons algorithm exceeded the limits on almost all aspects, e.g. 5.8% soft tissue voxels are out of limit for the expansion, the B-Spline and the SFBR both stayed within the limits for soft tissue and air cavities. The expansion and shear strain in the bony anatomy exceeded the limits for all algorithms. The average translivity exceeded the limit for SFBR, while it remained within limits for B-Spline and Demons.

The results of deforming the pCT to the CBCT gives the SFBR algorithm as the most promising algorithm.

Conclusions: Using the TEST method the accuracy of three different DIR algorithms could be quantified and compared in all image voxels (both in high and low contrast image regions). The B-spline algorithm gave the most accurate results for pCT to rCT deformations, while the SFBR algorithm performed best for pCT to CBCT deformations.

OC-0062

Imaging dose assessment for intrafraction motion management in ion beam therapy
E. Steiner1, B. Kostresivic1, M. Stock2, G. Baroni3, D. Georg1
1Medical University of Vienna, Dept. of Radiooncology, Vienna, Austria
2Medical University of Vienna, Dept. of Radiooncology and Christian Doppler Laboratory for Medical Radiation Research for Radiation Oncology, Vienna, Austria
3Politecnico di Milano, Dept. of Bioengineering, Milan, Italy

Purpose/Objective: Image guidance is crucial for assuring a safe and accurate delivery in particle therapy and advanced photon radiotherapy. However, kV based imaging systems for treatment planning, position verification and intrafraction motion management lead to an additional dose burden for the patient. An investigation of the imaging dose for various organs at risk (OARs) caused by different imaging protocols for lung was performed at a conventional radiotherapy department (CRD) and an ion beam center (IBC).

Materials and Methods: Imaging dose was measured utilizing thermoluminescent dosimeters (TLDs) in an Alderson Rando phantom with the isocenter in the snifter lung of the phantom. Two sets of TLD-100 chips (3x3x1 mm³; sensitivity within ±3 %) were chosen. Measurements were performed for 25 selected points on the skin or within OARs (in each point 3TLDs). For calibration 5 TLDs were irradiated in a Co-60 beam and 6 TLDs were used to account for background irradiation. Measurements were performed for:

- CRD: Elekta XVI planar kV: 120 kV, AP and LR, 5 mAs per image, 520FD
- ExacTrac planar kV+MV: 120 kV, right posterior oblique and left posterior oblique projections, each with 160 mAs, 160 ms
• Elekta XVI CBCT: 120 kV, 649 mAs, 649 frames, M20FO, 360° scan
• Elekta XVI fluoroscopy: 120 kV, AP, 1 mAs per frame, 5.5 Hz frame rate, exposure time of 3min, S20FO

IBC: Kawasaki robotic arm with Varian A-277 X-ray tube, B-130H housing and Varian PaxScan 4030D flat panel detector:
- planar kV: AP: 125 kV, 100 mA, 12 ms; LR: 125 kV, 160 mA, 25 ms
- CBCT: 120 kV, 3 mA, 10 Hz frame rate, 430 frames, scan from -100° to +100°

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 modality and the position of the OARs. The doses for volumetric CT). The unit was calibrated in accordance with the recommendations of AAPM TG-61. Both in-air and in-water calibrations were performed for small animal stereotactic irradiation (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 DOSXY2ncr 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 isodose 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**

J. van Hoof, P. Granton, F. Verhaegen

'Maastricht Radiation Oncology (MAASTRO), Physics, Maastricht, The Netherlands

**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 downscalled 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 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:**