of reduced overlap with healthy tissues. The PTV overlap with bladder and rectum was reduced from 108 to 60 ml and from 25 to 17 ml, respectively, as a consequence of tighter margins and the fact that smaller mpITV subranges were used in the plan library. The mean number of plans in the plan library was only 3.2 (range: 2-5) for the 5-mm updatable strategy. On average only 0-2 (mean 0.9) updates were required per patient during the fractionated treatment.

Table 1: Results of the simulations for the various library strategies

Library type/margins	Fixed 10 mm	Fixed 7, 5 and 10mm	Updatable 7 mm	Updatable 5 mm
Average volume of healthy tissue irradiated (ml)	409	288	282	229
Overlap with bladder (ml)	108	74	77	60
Overlap with rectum (ml)	25	17	16	13
Average # of plans	2	6	3.4 (2-5)	3.2 (2-5)
Average # of updates	0	0	0.9 (0-2)	0.9 (0-2)

Conclusions: Our results indicate that an updatable plan library can significantly reduce irradiated healthy tissue using only a limited number of extra plans. Because of the low number of library updates, and because the limited number of library plans, the proposed approach should be feasible in clinical practice.

Proffered Papers: Physics 8: Imaging: focus on QA and technical aspects

OC-0406

Efficient quality management program for long-term consistency of robotic image-guided small animal irradiators

N.P. Brodin[1], C. Guha[1], W.A. Tomé[1]
[1]*Albert Einstein College of Medicine, Institute of Onco-Physics, Bronx, USA*

Purpose/Objective: To develop a comprehensive long-term quality management program (QMP) for image-guided robotic small animal irradiators used in pre-clinical radiation therapy (RT) research. Modern pre-clinical RT research requires high precision and accurate dosimetry to facilitate the translation of research findings into clinical practice. Several systems are available that provide precise delivery and on-board imaging capabilities, creating the need for an efficient QMP.

Materials and Methods: Protocols were developed and implemented to assess the dose output consistency (based on the AAPM TG-61 protocol), cone-beam CT (CBCT) image quality and object representation accuracy (using a custom-designed imaging phantom with air cavities for measuring resolution consistency and materials of varying CT density), CBCT-guided target localization and consistency of the CBCT-based dose calculation. To facilitate an efficient read-out and limit the user dependence of the QMP data analysis, a semi-automatic image analysis and data representation program was developed in MATLAB. Details related to the proposed dosimetric and imaging tests are presented in Table 1.

Results: We present the results of the first 6 months experience using the suggested QMP for our small animal radiation research platform (SARRP), with data collected on a bi-monthly basis. We established that the dosimetric output consistency was within ±1 %, the consistency of the image resolution was within ±0.2 mm, accuracy of CBCT-guided target localization was within ±0.5 mm, and dose calculation consistency was within ±2 s (± 3 %) per treatment beam. There was considerable variation in image intensity across the different x-ray densities of the imaging phantom, exceeding ±1 standard deviation, something that was attributed to the detector calibration preformed before each quality assurance session.

Table 1. Recommended tests and tolerance levels based on our 6-month experience.

	Tests	Tolerance
Output consistency	Measure dose-rate the at isocenter using an appropriately calibrated ion chamber	± 1%
Image resolution consistency / Object representation	Use a CBCT scan of the imaging phantom to derive diameters of all resolution air cavities by vertical and horizontal line profiles. Derive distances between cavities from the same line profiles. Check the length and diameter of the imaging phantom in a sagittal slice.	± 0.2 mm for resolution ± 0.5 mm for distances ± 1.0 mm for object size representation
Accuracy of image-guided target localization	Locate a well-defined target using the high-CT density BB phantom and then verify that its location identified on the CBCT coincides with the radiation isocenter using the 5 x 5 mm² collimator at gantry angles 0° and 90°.	± 0.5 mm
Dose calculation consistency	Calculate a 4-field 10 x 10 mm² treatment plan for 10 Gy on a reproducible isocenter in the imaging phantom and record the treatment times.	± 2 s (± 3%) per treatment field

Conclusions: Based on our results we propose the tests and tolerance levels provided in Table 1 to be used with the proposed quality management program, on a monthly or bi-monthly basis. This should provide sufficiently rigorous quality assurance to detect inconsistencies in dosimetric or imaging parameters that are beyond the acceptable variability for a reliable and accurate pre-clinical radiation delivery system.

OC-0407

Monte Carlo simulation for imaging dose estimation: application to the Elekta XVI kV-CBCT

H. Chesneau[1], D. Lazaro[1], C. Lafond[2], O. Henry[2], J.P. Manens[2], V. Blideanu[1]
[1]*CEA LIST, DRT, Gif sur Yvette, France*
[2]*Centre Eugène Marquis, Medical Physics, Rennes, France*

Purpose/Objective: Cone-Beam Computed Tomography (CBCT) is progressively more used in clinical practice to ensure precision in target localization and patient positioning required by new radiotherapy treatment techniques. However, intensive use of image guidance procedures could add a significant extra dose to normal tissues and potentially amplify the risk for patients to develop radiation-induced cancer. Therefore, there is an increasing interest to evaluate the dose delivered by CBCT scans. The most accurate tool to evaluate this imaging dose is the Monte Carlo (MC) method. To this end, this study aims at developing a MC-based dose calculation tool to compute the imaging dose, and to validate it in pre-clinical conditions against dosimetric measurements.

Materials and Methods: The new version of the MC code PENELOPE developed in C++ in our lab was used in this study. A detailed modeling of the ELEKTA X-ray Volume Imaging (XVI) CBCT unit, including the incident electron source, the anode, the inherent and additional filters, the S20 and M15 collimator cassettes and the F1 bowtie filter, was performed. First, the XVI model was commissioned in static acquisition mode (2D) by comparing simulations results against measurements of Half Value Layers (HVL) in air, of depth dose curves normalized to 1 cm depth and dose profiles at 1 and 5 cm in depth in water. The HVL measurements were performed following the recommendations of the AAPM TG 61 using a Farmer ionization chamber (PTW, type 30013). The water measurements were carried out with a 0.3 cm^3 cylindrical ionization chamber (PTW, type 31003) and for

shallow depths with a Markus parallel plate ionization chamber (PTW, type 23343). Second, the rotation of the X-ray tube was implemented in the MC code to mimic the volumetric (3D) acquisition mode, whose dosimetric validation is currently undergoing.

Results: Dose measurements and MC simulation are in agreement: a passing rate greater than 95% and 82 % was observed for depth dose curves and dose profiles respectively, for local gamma-index criteria of 2%/2 mm (cf. Fig. 1.).

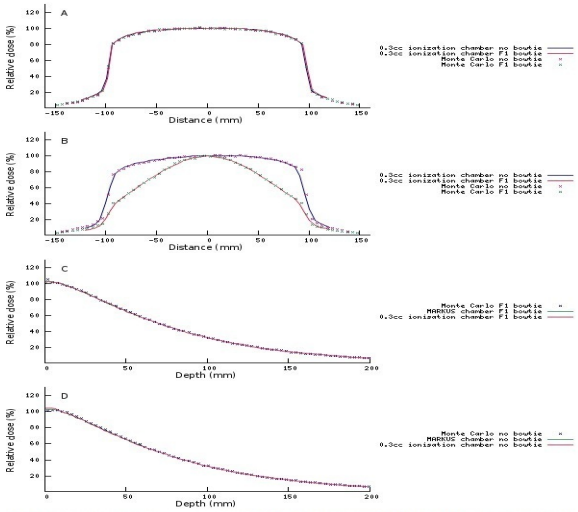

Fig. 1. Comparisons between measurements and MC calculations at 120 kV for the S20 collimator. Inline (Y) and crossline (X) profiles at 1 cm deep are shown in (a) and (b), respectively. Depth dose curves with and without bowtie are shown in (c) and (d), respectively.

Some discrepancies were noticed, in the first millimeters of the depth dose curves, resulting of difficulties to perform accurate measurements at the surface, even with a plate chamber. Finally, the HVL values obtained by simulation were in close agreement with measured values (cf. Tab. 1.).

Tab. 1. Measured and calculated HVL values at 120 kV with and without bowtie filter.

Beam quality	Experimental measurement *(mm of aluminum)*	MC simulation *(mm of aluminum)*	Relative difference *(%)*
120 kV without bowtie	7.04	6.87	2.5
120 kV F1 bowtie	8.04	7.71	4.3

Conclusions: The XVI MC model developed with PENELOPE was successfully validated in 2D mode against an extensive set of measurements, and preliminary results for the 3D acquisition mode are very encouraging. Future work includes a comprehensive validation of the simulation tool by comparing simulation results with dosimetric measurements in anthropomorphic phantoms.

OC-0408

Impact of prospective respiratory-gated 4DCT acquisition on thoracic image quality: a digital phantom study

K. Bernatowicz[1], P.J. Keall[2], A. Lomax[1], A. Knopf[1], P. Mishra[3], J. Kipritidis[2]

[1]*Paul Scherrer Institute (PSI), Proton Therapy Centre, Villigen PSI, Switzerland*

[2]*University of Sydney, Sydney Medical School, Sydney, Australia*

[3]*Harvard Medical School, Brigham and Womens Hospital, Boston, USA*

Purpose/Objective: To perform the first simulations of respiratory-gated 4DCT with an emphasis on lung image quality, which is important in performing dose calculations based on accurate estimates of lung volume and structure. We developed a novel simulation framework incorporating the digital eXtended Cardiac Torso (XCAT) phantom driven by patient tumor motion patterns.

Materials and Methods: Our simulations encompass three 4DCT acquisition modes featuring different levels of respiratory feedback: (i) 'conventional' 4DCT that uses a constant imaging and couch-shift frequency, (ii) 'beam paused' 4DCT that interrupts imaging to avoid oversampling at a given couch position and respiratory phase, and (iii) 'respiratory-gated' 4DCT that triggers acquisition only when the respiratory motion fulfills phase-specific displacement gating windows based on pre-scan breathing data. 8 lung cancer patients (14 fractions) with tumor motion displacement >5mm were selected for simulations and image quality was compared with the ground truth in terms of clinically relevant measures of lung image quality: threshold-based lung volume error, Dice similarity, false-positive and false-negative ratios. Moreover, acquisition time and the relative imaging dose (i.e. number of acquired images normalized to conventional method) were calculated.

Results: Averaged across all simulations and phase bins, respiratory-gating leads to small, but significant ($p<0.02$) reductions in lung volume errors (1.8% to 1.4%), false positives (4.0% to 2.6%) and false negatives (2.7% to 1.3%), fig. 1(a-d). For a typical 6 L lung, these percentage reductions correspond to gating reducing image artifacts by 24-90 cm3 of lung tissue. Similar to earlier studies, gating reduced patient image dose by (11.1±9.2)%, but with scan time increased by up to 135%. Beam paused 4DCT did not significantly impact normal lung tissue image quality, but did yield similar dose reductions as for respiratory-gating, without the added cost in scanning time.

Conclusions: Respiratory-gated 4DCT can reduce thoracic

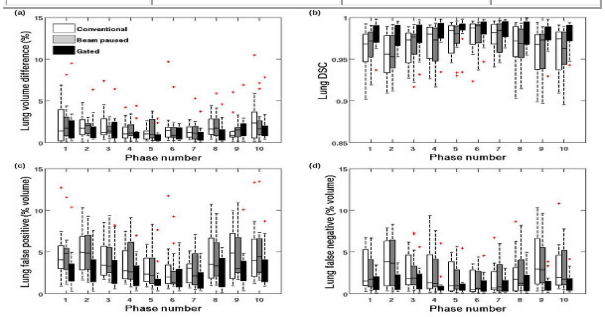

image artifacts compared to conventional acquisition. This image improvement could have important implications for dose calculations based on 4DCT. Where image quality is less critical, beam paused 4DCT is a simple strategy to reduce imaging dose without sacrificing acquisition time.

OC-0409

Deformable image registration with guaranteed local rigidity

L. König[1], A. Derksen[1], S. Heldmann[1], N. Papenberg[1], J. Modersitzki[1], B. Haas[2]

[1]*Fraunhofer MEVIS, Project Group Image Registration, Lübeck, Germany*