

A small animal image guided irradiation system study using 3D dosimeters

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Abstract. In a high resolution image-guided small animal irradiation platform, a cone beam computed tomography (CBCT) is integrated with an irradiation unit for precise targeting. Precise quality assurance is essential for both imaging and irradiation components. The conventional commissioning techniques with films face major challenges due to alignment uncertainty and labour intensive film preparation and scanning. In addition, due to the novel design of this platform the mouse stage rotation for CBCT imaging is perpendicular to the gantry rotation for irradiation. Because these two rotations are associated with different mechanical systems, discrepancy between rotation isocenters exists. In order to deliver x-ray precisely, it is essential to verify coincidence of the imaging and the irradiation isocenters. A 3-D PRESAGE dosimeter can provide an excellent tool for checking dosimetry and verifying coincidence of irradiation and imaging coordinates in one system. Dosimetric measurements were performed to obtain beam profiles and percent depth dose (PDD). Isocentricity and coincidence of the mouse stage and gantry rotations were evaluated with starshots acquired using PRESAGE dosimeters. A single PRESAGE dosimeter can provide 3-D information in both geometric and dosimetric uncertainty, which is crucial for translational studies.

1. Introduction

In order to mimic modern clinical radiotherapy in small animal disease models, several practical conditions impose that a dedicated small animal research platform is required. This means that radiation beams not only need to be downscaled in geometry, but also in energy. Furthermore, the technical precision required to deliver millimetre sized beams to regions within a small animal exceeds the tolerances needed in patient radiotherapy [1]. A few such small animal research platforms have been developed, the one used in this study is SARRP. It is a novel and complete system capable of delivering multidirectional, kilo-voltage radiation beams to targets in small animals under CBCT image guidance [2].

The quality assurance for SARRP includes measurements of absolute dose rates, beam profiles, and central axis percent depth dose (PDD) curves. In this study three dosimetric tools were employed: a farmer type ionization chamber (N30013, PTW), radiochromic EBT2 films, and PRESAGE 3-D [3] dosimeters with optical CT scanner (OCTOPUS, MGS Inc.). The ion-chamber was used to obtain absolute dose rates. Films were used to determine beam profiles and PDD for all fields. Film PDD measurements were challenging because of the difficulty of precise alignment to the small field. In addition, obtaining accurate data using films requires following a strict scanning protocol. Independent measurements were also performed using PRESAGE 3-D dosimeters with optical CT scanner [4-8].



PRESAGE dosimeters are much more efficient compared to film because all parameters of interest can be obtained from a single dosimeter and a single scan, and set-up-errors are negligible because the entire dose distribution is captured in the dosimeter.

2. Materials and Methods

In SARRP the gantry isocenter is at 35 cm from the focal spot. The combination of gantry rotation and mouse stage motion facilitates the dose delivery. The collimator accommodates a range of brass inserts: two square ones 10x10 and 5x5 mm², and two circular ones 1 and 0.5 mm in diameter. All irradiations in this work were performed with a 225 kVp and 13 mA beam. For CBCT imaging the gantry and a flat panel detector were set at opposite horizontal positions of 90° and 270° respectively. 360 projection images were obtained by rotating the mouse stage. CBCT imaging was performed with 50-100 kVp and 0.8mA beams.

The output was measured using a calibrated ion-chamber following the AAPM task group report 61 [9]. The field size was 17x17cm² and the depth and source-surface distance (SSD) were 2 and 33 cm, respectively. The output calibration phantom assembly consisted of three plastic water slabs (in order from top to bottom of stack): 20x20x1 cm³, 20x20x2 cm³ (with a chamber hole bored out at 1 cm depth), and 20x20x1 cm³.

EBT2 films were calibrated under the same condition as ion-chamber before it was used for quality assurance measurement. The calibration consisted of 15 dose points spanning 0 to 600 cGy. The exposure times to best approximate the target doses were determined from ion-chamber dose rate measurement. The exposure times were then applied to the ion-chamber measured dose rate to determine the absolute doses to be delivered to films. After film calibration, beam profiles and PDD values for 10x10 mm² field were measured using films loaded on the phantom stack at the following depths: 0 (surface dose measurement), 5, 10, 15, 20, 30, 40 and 50 mm. For comparison, PDD curves were also measured from films aligned vertically along the central beam axis using side lasers. Isocentricities of the mouse stage and gantry rotations were evaluated using starshots from films.

The same measurements were performed using four cylindrical PRESAGE dosimeters with 6 cm diameter and 7 cm height. PRESAGE dosimeters were approximately placed at the center on mouse stage with guidance of crossed lasers. The first dosimeter was used to establish a response curve. Dose rate for a given depth and field size can be calculated from the film calibration. Therefore dose delivered to the dosimeter can be calculated for that depth and field size with given exposure time. The linear optical density and dose response of PRESAGE dosimeter was confirmed. The rest of the dosimeters were used to measure beam profiles, PDD, and coincidence of the mouse stage and gantry rotation isocenters. The readouts of the irradiated PRESAGE dosimeters were performed with the optical CT scanner, and data were reconstructed with a resolution of 1 mm³ voxel size using an in-house program (FBP) written in Matlab. The data readout time and reconstruction time are ~10 hours and ~1.5 minutes respectively.

3. Results and Discussion

From Ion-Chamber measurement, the output at isocenter is 3.9 Gy/min. A calibration curve was obtained from films. Beam profiles for 10x10 mm² field were measured at three depths using films orientated perpendicular to the beam, as shown in figure 1 (A). 20%-80% penumbra value is 0.5mm. Full-width-half-maximum (FWHM) of the beam profiles slightly increases over depths due to scattering, the FWHM difference is 0.5mm between depths 0 and 20mm. Figure 1 (B) shows measured PDD for 10x10 mm² field. The solid curve is from film vertically aligned with beam central axis. The markers are from the axial films at multi-depths, which are considered as the standard method for measuring PDD. The downside of axial film method is time consuming. The PDD measurements using films highlight the need for the 3-D dosimeters, which avoids the alignment error issues and is very efficient. The isocentricity measurements using films for gantry rotation and mouse stage rotation are summarized in table 1.

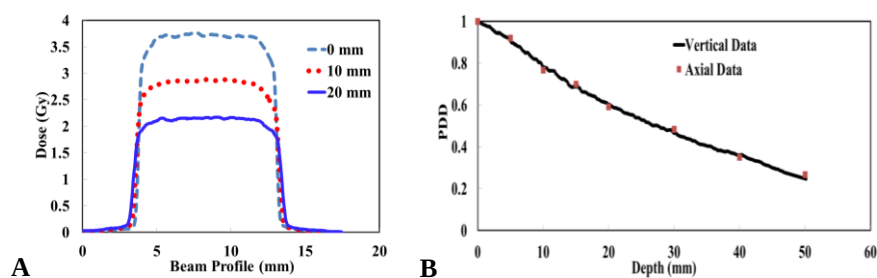


Figure 1. A. Beam profiles at depths of 0, 10 and 20 mm for 10x10 mm² square field; B. The PDD curve obtained using films.

Figure 2 shows the linear optical density and dose response at depth of 20 mm in the PRESAGE dosimeter.

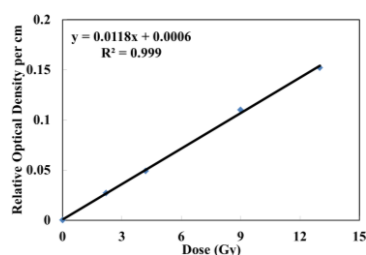


Figure 2. PRESAGE dosimeter calibration curve determined from four dose levels.

Figure 3 (A) shows the central slice of the reconstructed dosimeter image. The dashed lines indicate the locations of two illustrative axial slices at the depths of 10 and 20mm. Figure 3 (B) shows the axial slice at the depth of 20mm. Beam profiles along central cross lines of 10x10 mm² field are shown in figure 3 (C). The 20%-80% penumbra value is 1.4mm, which is larger than the one obtained using film. The FWHM difference is 0.25mm between depths 10 and 20mm.



Figure 3. A. Central slice of reconstructed dosimeter image; B. Axial slice at the depth of 20mm; C. Beam profiles along central cross lines of the field at depths of 10 and 20mm.

Figure 4 compares the PDD curves obtained using film and dosimeter irradiated with 10x10 mm² field. PDD from film and PRESAGE dosimeter agree within 3% up to the depth of 3cm.

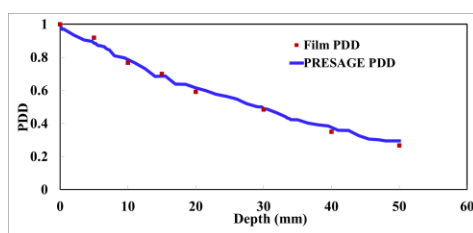


Figure 4. PDD obtained using film and dosimeter irradiated with 10x10 mm² field.

Figure 5 (A) shows the irradiated dosimeter for evaluation of isocentricity and coincidence of mouse stage and gantry rotations. Figures 5 (B-C) show beam trajectories delivered at 5 different angles in both irradiation and CBCT imaging coordinates. Table 1 summarizes the obtained results from films and PRESAGE dosimeters.

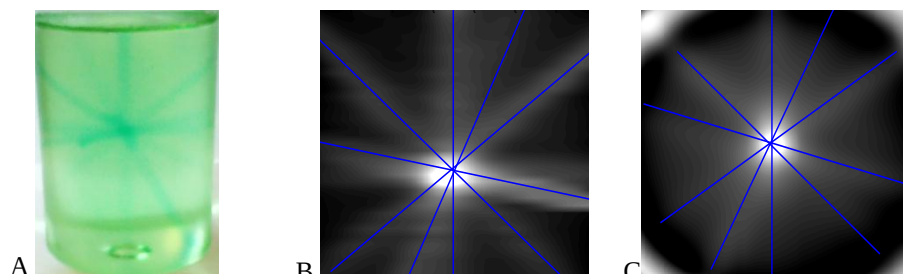


Figure 5. A. Irradiated dosimeter for both gantry and mouse stage isocentricity measurement; B. Beam trajectories from gantry rotation; C. Beam trajectories from mouse stage rotation.

Table 1. Comparison between films and PRESAGE dosimeters

	Isocentricity of irradiation coordinate (mm)	Isocentricity of CBCT imaging coordinate (mm)	Experiment setup time (mins)	Coincidence of Irradiation and imaging isocentricity
Dosimeters	1	1.02	10	0.8
Films	1.13	1	90	NA

This study presents a comprehensive commissioning method using 3-D PRESAGE dosimeters. Both of film and PRESAGE dosimeter measurements were found to be valuable to ensure accurate and comprehensive commissioning. Good agreement was observed between film and PRESAGE dosimeter measurements. However, film measurements are time consuming due to the difficulty of alignment in small fields, and labour intensive when multi-plane data are required. The PRESAGE dosimeter can be more useful in precise verification of targeting for a small animal irradiation research.

4. References

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