Assessing CBCT-based patient positioning accuracy on the Gamma Knife Icon\textsuperscript{TM} via Presage\textsuperscript{®} 3D absolute dosimetry

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Abstract. Cone beam computed tomography (CBCT) imaging has been implemented on the Leksell Gamma Knife Icon\textsuperscript{TM} for repeated patient positioning in mask-based Gamma Knife radiosurgery. The purpose of this study was to evaluate the accuracy of the CBCT-based patient positioning on the Gamma Knife Icon\textsuperscript{TM}. Two Presage phantoms of 15 cm diameter and 10 cm height were irradiated with identical shot placements on an Acoustic Neuroma target with the same prescription dose following standard mask-based treatment workflow according to two different fraction schedules: a single fraction of 7.5 Gy and 5 fractions with 1.5 Gy fraction dose. On the top and the bottom portions of each phantom, 8 single 16 mm collimator shots were delivered with maximum doses from 2 Gy to 20 Gy for dose sensitivity calibration. The irradiated Presage phantoms were scanned and analyzed using an OCTOPOUS optical CT scanner. Both the absolute dose distributions and the relative dose distributions for the Acoustic target on each phantom were compared with those from the treatment planning system. The relative dose distribution from the single fraction irradiation agrees better with the planning system than the 5 fraction irradiation, indicating noticeable change in the dose distribution caused by the phantom positioning/repositioning process. No difference between the absolute dose distributions from the two phantoms could be identified because of the large uncertainty in the experiment data.

1. Introduction
The Leksell Gamma Knife Icon\textsuperscript{TM} is the newest radiation therapy treatment machine manufactured by Elekta AB (Elekta AB, Stockholm, Sweden) for stereotactic radiosurgery on intra-cranial diseases [1]. The Icon\textsuperscript{TM} Gamma Knife provides the capacity to perform single fraction and fractionated Gamma Knife radiosurgery using a thermal plastic mask-based head immobilization and the CBCT imaging for repeated patient positioning. The CBCT imaging technique introduced by Jaffrey et al [2] has become a standard medical imaging modality for patient positioning in external beam radiation therapy using linear accelerators. The on-board CBCT imaging module provides a treatment machine-based measurement tool that allows for a 3D visualization of the patient positioning on the treatment table. The CBCT imaging technique has been applied to many patient immobilization methods including the mask fixation that is now implemented on the Gamma Knife Icon\textsuperscript{TM} [3].

Several dose sensitivity calibration methods have been studied for optical CT-based 3D radiation dosimetry [4]. In the early investigations of gel dosimetry, the dose responses of the dosimeters were usually obtained from measurements across a series of small size dosimeters irradiated to graded doses [5-7]. The resultant dose response curve could then be used to calibrate the dose response of large gel
phantoms. Several groups have observed dose deviations between calibration vials and larger phantoms originating from the same batch of gel with different potential causes [8-9]. In particular, De Deene et al shown that the temperature history during and after the gel fabrication process has a significant influence on the dose response and it may be difficult to keep the temperature history after fabrication similar for both the gel dosimeter phantom and the calibration vials because of the differences in phantom size [9]. Attempts were also made to implement calibration approaches utilizing multiple small photon fields irradiated to grades dose or electron depth dose curve from a calibration phantom of the same size as the dose verification phantom [10-12]. These methods were intended to minimize the temperature effect resulting from the difference in phantom size but introduced additional uncertainty in the dose calibration process such as scattered dose in the multiple field approach [11] or energy dependence of the gel dose response. A commonly used method for 3D radiation dose comparison is to do a relative dose comparison which normalizes a measured 3D dose distribution to two points of a planned 3D dose distribution [13].

In this study, we will perform a preliminary evaluation of the CBCT-based patient positioning accuracy on the Gamma Knife Icon™ using a dose sensitivity calibration method that does not require any calibration phantom.

2. Materials and Methods

The Presage dosimeters (Heuris Phanma LLC, Skillman, NJ) were formulated with tetrabromomethane, polyurethane and poured into a silicone mold to cure under 50 psi for 5 days. Two cylindrical Presage phantoms at approximately 1.8 kg with 15 cm diameter and 10 cm height from the same batch were used for this study. The Presage phantoms were imaged using a GE LightSpeed CT simulator (General Electric Co, Boston, MA) with 1 mm slice thickness. The CT images were transferred to the Gammaplan treatment planning system and defined as preplanning preference for mask-based treatment. The shot placement in a Gamma Knife treatment plan for an Acoustic Neurama patient was used for the phantom study. The stereotactic coordinates and the weighting factors for 9 treatment shots were reproduced on both Presage phantoms. The prescription doses for the two phantoms were 7.5 Gy to the 50% isodose line in one fraction and in 5 fractions. On the top and the bottom portions of each phantom, 8 single 16 mm collimator shots were planned with maximum doses from 2 Gy to 20 Gy for dose sensitivity calibration purpose. The overall contribution from these calibration shots to the Acoustic Neurama target in the central region of the phantoms is less than 3%. A head cushion and a mask were made for one phantom and used during the irradiation of both phantoms. For the single fraction irradiation, a reference CBCT was acquired and registered with the planning CT images for the definition of the stereotactic coordinate system. A setup CBCT image set was acquired subsequently for couch alignment during the dose delivery. For the 5 fraction delivery, the mask and the phantom were taken out of the adaptor after the first fraction and the process repeated from setting up the phantom on the adaptor.

The irradiated Presage phantoms were scanned using an OCTOPOUS optical CT scanner with same scanning parameters including 1 mm slice thickness and 1 mm resolution. On the center slice of the reconstructed images for each 16 mm shot, 5 readings were taken from the central region of the dose distribution and an averaged image intensity value was calculated. A one to one correspondence between the averaged image intensity and the delivered maximum dose was then established to obtain a calibration curve. The calibration curve was then used for the calculation of the absolute dose distribution within the phantom. For comparative purpose, relative dose comparison was also made between the two phantoms and the planning system.
3. Results and Discussion

Figure 2 shows the dose response curves for the two Presage dosimeters. Several single 16 mm shots were too close to the top surface and it was difficult to find a region of uniform dose to take 5 readings from these shots because of the unevenness of the phantom surfaces. Therefore, 3 data points for the calibration curve on each phantom were rejected. Both calibration curves show good dose response linearity. When fitted to straight lines, the slopes of the two calibrations curves are different by 4.8%. The background image intensity is significantly different even though the two phantoms were from the same batch and the scanning parameters were the same.

Figure 3 compares the absolute dose distributions from the Presage phantoms to those from the planning system for the central slice in axial plane. Both the single fraction and the 5 fraction isodose lines are in reasonable agreement with the planning system. The single fraction absolute dose distribution (blue lines in Figure 3a) appears less noisy than the 5 fraction absolute distribution (green lines in Figure 3b) but the shape of the two set of isodose lines, especially the 7.5 Gy prescription isodose lines are similar.
Figure 3. Comparison of the absolute isodose lines (13 Gy, 7.5 Gy, 5 Gy, 3.5 Gy) from the Gammplan planning system (red lines) and the Presage phantoms for the central transverse slice; one fraction irradiation: blue lines; 5 fraction irradiation: green lines.

Figure 4 compares the relative dose distributions from the Presage phantoms to those from the planning system for the central slice in axial plane. The isodose lines from the one fraction experiment clearly agree better with the planning system than the 5 fraction experiment.

Two comments can be made about the results from this preliminary study. First, there seem to be some non-negligible differences between the isodose distributions from the single fraction irradiation and the 5 fraction irradiation. The differences may be mainly related to the cumulative effect from multiple times of CBCT-based phantom repositioning. The change in isodose distribution, especially the 50% prescription isodose line may have significant clinical impact for certain treatments. Therefore, more studies are needed to quantify this effect for optimal clinical outcome. Second, the change in the isodose distribution was not detected by the absolute dose comparison because the uncertainty in the resultant absolute dose was larger than the dose distribution change from the phantom repositioning. One possible cause of the large uncertainty is that the doses delivered to the Presage dosimeters were not high enough. The reconstructed images for the two Presage phantoms were quite noisy indicating a suboptimal signal to noise ratio. The non-uniform distribution of the chemical components inside a
Presage phantom and/or the differences in the temperature history at different regions of the phantom may also contribute to the large uncertainty in the absolute dose distribution.

4. Conclusion
We have performed a preliminary evaluation of the CBCT-based patient positioning accuracy on the Gamma Knife Icon™ using optical CT-based Presage dosimetry. The relative dose comparison shows a clear effect in the dose distribution that can be attributed to the phantom positioning/repositioning process. No difference between the absolute dose distributions from the fractionated and single fraction treatment were observed because of the large uncertainty in the experiment data.

5. References
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