3-D dosimetric evaluation of 2.5 mm HD120® multileaf system for intensity modulated stereotactic radiosurgery using optical CT based polymer gel dosimetry

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Abstract : A Trilogy TX equipped with a 2.5 mm HD120® multileaf collimator system is available for the treatment of radiosurgery and IMRT. In this study, we evaluated the 3-D dosimetric impact of leaf width on an IMRT radiosurgery plan by comparing the target coverage and the dose gradient around the target, produced from both a 2.5 mm HD120® high-definition MLC system and a 5mm-leaf-width millennium 120 MLC system, using an optical CT based polymer gel dosimetry system. The 2.5 mm MLC improves target conformity and surrounding tissue sparing when compared to that of 5 mm MLC.

1. Introduction
Radiosurgery, either cranial or extracranial, is a procedure that precisely delivers large radiation doses to tumors and other relevant anatomical targets in a single fraction or in a small number of fractions (typically up to five). The goal of a non-invasive stereotactic radiosurgery (SRS) is to destroy, or make inactive, the target without damaging surrounding healthy tissue and without involving traditional surgery. The desirable conditions of dose distribution in SRS are: a). The shape of the isosurface defined by the prescription dose conforms to the outline of the target; b). Nonuniform dose distribution throughout the target volume and the location of the hot spot are clinically acceptable; and c). A rapid falloff of dose from the target volume to surrounding healthy tissue following the criteria that are clinically important. Therefore, the success of stereotactic radiosurgery requires precise targeting and rapid dose falloff in surrounding normal tissues. The ability to deliver an accurate desired dose to the target requires precise volume targeting. To achieve this, an accurate patient positioning, immobilization, and compensation for organ motion is essential. Recent developments in geometric accuracy of linear accelerator and immobilization devices as well as imaging-guided radiotherapy systems have improved the spatial accuracy when treating patient with stereotactic radiosurgery. Various linear accelerator radiosurgery techniques include multiple non-coplanar arc fields using circular cones, multiple static conformal beams using either blocks or multileaf collimator (MLC), and intensity modulated fields using dynamic MLC. There have been reports on dosimetric comparisons among these radiosurgery techniques [1-3]. In general, via modulation of the beam intensity of each field, the use of IMRT for radiosurgery has the features of good dose conformity and steep dose gradients for organ sparing. In addition, inverse treatment planning for IMRT replaces the traditional forward planning for other radiosurgery techniques, which potentially can reduce the treatment
planning time for complex cases [4] While it is still not clear as to which technique is superior for SRS, this study was focused on the dosimetric impact of leaf width, using a Varian Trilogy TX vs. a Varian 21 EX linear accelerator. The Trilogy TX has a 2.5 mm HD120® high-definition multileaf collimator system and the 21EX has a 5 mm millennium multileaf collimator system. We evaluated the 3-D dosimetric impact of leaf width on an IMRT radiosurgery plan by comparing the target coverage and the dose gradient around the target, produced from both a 2.5 mm HD120® high-definition MLC system and a 5mm-leaf-width millennium 120 MLC system, using an optical CT based polymer gel dosimetry system.

A 3-D polymer gel dosimeter, with various techniques for imaging the dose distribution, has been applied to verify the complex 3-D dose distribution [5-9]. Our previous studies have shown that our optical CT based polymer gel dosimetry can be used for dose verification in 3DCRT, IMRT, and SRS. In this study, we investigated the detailed dosimetric impact on the stereotactic radiosurgery using a 2.5 mm HD120 multileaf system for a 2.5 cc small brain lesion.

2. Materials and Methods

In this study, a polymer gel dosimeter and an optical CT scanner have been employed to implement 3-D dose distribution measurements. A plastic cylinder of 15 cm diameter and 14 cm height, filled with BANG®3 polymer gels (MGS Research, Inc., Madison, CT) and modified to optimal dose-response characteristics, was used for dose measurement. A slice thickness of 2.5 mm without spacing was used for CT simulation on both the patient and the gel cylinder. The DICOM CT images were then sent to the treatment planning system through the network. The Varian Eclipse treatment planning system was used to design the IMRT radiosurgery plan for a patient with a 2.5 cc small brain tumor treated with 6 MV photon beams.

To test the impact of leaf-width on the target coverage and the dose fall-off in the immediate vicinity of the target, a 2-mm margin outside the target was outlined to form a volume of avoidance. Dose-volume constraints for the optimization process include a) 100% of the target volume being covered by 100% of the prescription dose, b) The maximum dose to the target is limited to 110%, and c) ≤30% of the avoidance volume should receive ≥60% of the prescription dose. The inverse planning was first performed for the patient with the Trilogy TX HD120®. The dose calculation algorithm in the treatment planning system is based on the AAA model with an inhomogeneity correction. In the process of selecting the best treatment plan for the purpose of dosimetric comparison between 2.5mm and 5mm MLCs, one strategy was to give the highest priority to target coverage and dose distribution conformity while simultaneously minimizing the dose to the volume of avoidance. The other approach was to give a higher priority to the dose constraint for the OAR (avoidance volume, in this case) as long as 100% of the target receives an acceptable minimum dose (e.g. 100% of the target volume receiving ≥95% of the prescription dose). For instance, this can happen when the dose to the organ at risk (OAR) is the limiting factor for the treatment plan. For the gel study we selected the latter as the criteria for planning, as the difference in target coverage between two MLC systems can be verified from the gel measurements. Once the “best” plan was identified, the same fluence map file was used to recalculate the dose distribution using the 21EX 5 mm millennium 120 MLC.

The leave sequence files and monitor units for the patient plans from both 2.5 mm HD 120 and 5mm millennium 120 were then transferred to the gel phantom to generate a hybrid phantom plan. The gel irradiation was performed under the same set-up geometry as used in the hybrid phantom plan. The set-up geometry of the gel measurement was verified with source-to-surface distance from irradiation gantry angles.

Two plastic cylinders of 15 cm diameter and 14 cm height, filled with BANG polymer gel, were used to verify the 3-D dose distributions from two MLC systems. One gel was irradiated with the plan generated from Trilogy TX with a 2.5 mm MLC system. One gel was irradiated with the plan generated from 21EX with a 5mm MLC system.

In order to correlate the optical density response of the gel with radiation dose, the same type of cylinder containing the same batch of gel was irradiated with a 16 MeV electron beam, with 6 x 6
cm cone, to a known dose at the depth of dmax. The optical density at a specific depth and the PDD table of the electron beam can be used to obtain the optical density dose response of the gel. The gel sample was scanned with 1 mm pixel resolution using a commercial optical CT scanner, OCTOPUS™ (MGS Research Inc., Madison, CT). Details of the operating principles, 3-D dose reconstruction, and instrument architecture of the optical scanner were described previously [6].

3. Results and Discussion

The gel samples for the hybrid phantom irradiation and the gel sample for the calibration of optical density dose response were from the same batch. The optical density versus dose was found to be linear in the dose range of 2-20 Gy. Figure 1 shows the dose-volume histograms (DVHs) for the target volume and avoidance volume, generated from both Trilogy TX (2.5 mm MLC) and 21EX (5 mm MLC) with the same fluence map files. As shown in Fig.1a, the highest priority during the treatment planning was given to target coverage while trying to minimize the dose to the avoidance volume. While 98.5% of the target volume received ≥100% of the prescription dose from both machines, the avoidance volume consistently received more dose at all dose levels from 21EX plan than from Trilogy. Furthermore, the target dose from 21EX is also less uniform. Fig. 1b shows the plan comparison with highest priority given to the avoidance volume (OAR). When limiting 30% of the avoidance volume to receive ≥60% of the prescription dose, only 87% of the target volume can be covered by the prescription dose from 21EX (5 mm MLC). Monk et al. [3] reported that, based on the treatment planning study of 14 clinical cases, the micro-MLC (3 mm) can improve both PTV conformity and surrounding tissue sparing when compared to that of a standard linear accelerator using 5 mm MLC for intracranial stereotactic radiotherapy. However, the comparison presented in Figure 1 and that from Monk et al. [3] are purely based on a treatment planning study. For such a small lesion (2.5 cc) in this study, one may question the clinical importance and the dosimetric accuracy for the above difference observed between 2.5 mm MLC and 5 mm MLC. Putting aside the clinical implication, the gel dosimeter was used to investigate the dosimetry accuracy in the treatment planning system as well as the MLC comparison.

Figure1. Comparison of the DVHs from Eclipse treatment planning system for Trilogy and 21EX.

Figure 2 shows dose distribution at the central slice in axial plane between the gel measurements and the treatment planning calculations. Both measured and calculated dose distributions are in reasonable agreement for both machines. However, the isodose lines from the gel measurements show more variation than those from the planning system calculation, and this trend is more significant for the Trilogy TX 2.5 mm MLC. These discrepancies may be partly attributed to the fact that the calculation
grid for the planning system is 2.5 mm yet the resolution of gel measurements is 1 mm, as well as the Trilogy TX having a smaller leaf width. As shown in Fig. 1b, the target coverage is lower for the plan generated with the 21EX 5mm MLC.

Figure 2. Comparison of the isodose lines (110, 100, 90, 80, 50, and 30 percent) from the Eclipse planning system (green lines) and the gel experiments for the central transverse slice. Trilogy experiment: red lines; 21EX experiment: black lines.

Figure 3 displays the dose distribution from gel measurements in the axial plane at 3 mm inferior from the central slice, where the target is still well covered by the Trilogy TX 2.5 mm MLC; whereas with the 21EX 5mm MLC the target coverage is appreciably lower. It was noted that the target volume in study changes significantly from this slice to the next inferior slice. The 5 mm leaf width from 21EX could not provide the desired dose conformity for such a drastic change in target shape. As a result, both the target volume and the avoidance volume received a higher dose compared to those from the Trilogy TX, as demonstrated in Figure 1b. The other alternative was to renormalize the dose distribution in order to achieve the dose constraint for the avoidance volume but at the same time miss part the target coverage, as shown in Fig. 1a. Another desirable dosimetric feature is the dose falloff outside the target area. The dose distributions at 15 mm inferior to the central slice are shown at Figure 4. The steeper dose falloff from the 2.5 mm MLC than that of the 21EX can be partly attributed to the smaller penumbra for the 2.5 mm HD 120.
Figure 3. Isodose distribution (100, 80, 60, and 40 percent) from the gel experiments for the transverse slice that is 3 mm inferior to the central slice. Trilogy experiment: red lines; 21EX experiment: black lines. The green line is the PTV on this slice.

Figure 4. Isodose distribution (80, 60, and 40 percent) from the gel experiments for the transverse slice that is 15 mm inferior to the central slice. Trilogy experiment: red lines; 21EX experiment: black lines.

4. Conclusion
We have evaluated the dosimetric impact of leaf width on an IMRT radiosurgery plan by comparing the target coverage and the dose gradient around the target, produced from both a 2.5 mm HD120® high-definition MLC system on the Trilogy TX and a 5mm-leaf-width millennium 120 MLC system at 21EX. The 3-D dose distributions from the treatment planning were verified using an optical CT based polymer gel dosimetry. The 2.5 mm MLC improves target conformity and surrounding tissue sparing when compared to that of 5 mm MLC.

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