3D verification of a prostate IMRT treatment by polymer gel-dosimetry and optical-CT scanning

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1. Introduction

A laser-based optical-CT scanning system has been developed in our laboratory with the capability for high resolution 3D dosimetry. Basic characterization of the performance of the scanner, presented in previous work \cite{1,2} showed that relative 3D dose mapping with accuracy $\geq 96\%$ at a spatial resolution of 1 mm\textsuperscript{3} was a feasible goal. Here we present initial clinical application of the system to verify a 5 field IMRT prostate patient treatment plan.

2. Methods

The optical-CT scanner is shown in figure 1. Several improvements in scanner design were incorporated for this work. Artificial asymmetries in projection profiles were minimized by eliminating optical components with sensitivity to small deviations in angle of incident light, and by mounting the field photodiode on the traveling (scanning) arm such that the similar optical path-length was maintained between the gel-dosimeter and the field photodiode. The motion control and data acquisition components were rebuilt using commercial hardware (National Instruments, controller PXI-7344, driver MID7604, and data-acquisition PXI-6052 – 16bit 333 kS/s). Data acquisition and motion control was combined in a Labview 7 express software.

The prostate IMRT plan is shown in figure 2, and consisted of five 18MV step-and-shoot IMRT beams created using the Pinnacle treatment planning system. The entire plan used to treat the patient was copied, without any changes to the segments and beams, and recalculated onto a CT scan dataset of a 3 l volume gel-dosimeter with cylindrical dimensions of 17 cm diameter, and 12 cm height. The IMRT plan was then delivered to the gel-dosimeter via an Elekta Linac and optically scanned 48 hours post-irradiation with in-plane resolution of 1 mm\textsuperscript{2} and axial resolution of 3 mm. Each slice was scanned using 120 projections with 0.5 mm laser increments along each projection. Novel correction techniques were applied to the optical-CT projections to minimize corrupting effects of refraction and reflection. Three fiducial marks placed on the phantom enabled precise registration between the measured and planned dose distributions. The measured optical attenuation maps were converted to dose using a calibration curve (figure 3) obtained from irradiating and scanning an identical flask which had received calibration irradiations.
Figure 1. Upgraded optical-CT scanning system with laser diode (L), polarizer (P), filter (F), traveling post-mounted mirror (M), gel dosimeter (G) mounted from above to rotation/vertical translation stage, photodiode (D) detector mounted on traveling arm, control (C) and driver hardware.

Figure 2. Pinnacle isodose distributions through a common slice from (a) the original prostate patient treatment plan (consisting of a 5 field IMRT Tx), and (b) recomputed isodoses of the same plan, with identical beam orientations and segments etc, for the 17 cm diameter gel dosimeter. The prescription (total MU’s) was scaled in the latter so the dose matched the dynamic range of the gel and scanner.
Figure 3. An identical gel-dosimeter was used for calibration of optical attenuation to dose. (a) optical-CT scan of axial slice through the dosimeter showing the 6 radiosurgery calibration irradiations delivering doses in the range 0–1.5 Gy. A linear relationship between attenuation and dose was observed (b). The clear band of gel on the inside of the flask is attributed to localized oxygen contamination through the flask walls.

3. Results and discussion

Dosimetric evaluation was performed using a dedicated 3D dosimetry verification software DOSEQA [3] incorporating profiles and maps of distance–to-agreement, dose difference, and the gamma parameter [4] (figures 4, 5 and 6). The relative merits of these figures in regard to clinical evaluation will be discussed. The 3D measured dose distribution was registered to the planned dose distribution by aligning 3 fiducial marks on the side of the dosimeter. Close agreement between measured and planned distributions was observed in the high dose regions (>50% isodose line). Systematic overestimation of the measured dose by up to 6% of $D_{\text{max}}$ was observed at lower doses the causes of which are under investigation.

Figure 4. Isodose comparison of measured (grayscale) versus planning (red) dose in three orthogonal slices. The planning dose distribution was obtained from Pinnacle.
Figure 5. Planning system (red) and optical CT (black) dose profile comparison across an axial slice (blue). The left image shows split screen comparison of the two distributions.

Figure 6. Planning system/Optical CT split screen display of a single slice and three modes of analysis (gamma map, dose difference, and distance-to-agreement DTA).

4. Conclusions

High resolution 3D gel dosimetry by optical-CT scanning provides a technique with unprecedented ability for the comprehensive verification of complex radiation treatments. Accurate 3D gel-dosimetry requires careful characterization of both the optical-CT scanner and the response of the gel.

References

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