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Physics Contribution

Distance-to-Agreement Investigation of Tomotherapy's Bony Anatomy-Based Autoregistration and Planning Target Volume Contour-Based Optimization

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Summary

This study compares 4 degrees-of-freedom (dof) bony anatomy-based autoregistration and the idealized contour-based optimization in compensating for the setup errors due to pitch and yaw. We analyze distance-to-agreement (DTA) of the PTV determined by the shifts. We find that on average there is only approximately 1-mm difference in the maximum DTA between the 2 4-dof optimizations. We also find that among the uncorrectable setup parameters, the pitch deviation is more significant than yaw.

Purpose: To compare Tomotherapy's megavoltage computed tomography bony anatomy autoregistration with the best achievable registration, assuming no deformation and perfect knowledge of planning target volume (PTV) location.

Methods and Materials: Distance-to-agreement (DTA) of the PTV was determined by applying a rigid-body shift to the PTV region of interest of the prostate from its reference position, assuming no deformations. Planning target volume region of interest of the prostate was extracted from the patient archives. The reference position was set by the 6 degrees of freedom (dof)—x, y, z, roll, pitch, and yaw—optimization results from the previous study at this institution. The DTA and the compensating parameters were calculated by the shift of the PTV from the reference 6-dof to the 4-dof—x, y, z, and roll—optimization. In this study, the effectiveness of Tomotherapy's 4-dof bony anatomy−based autoregistration was compared with the idealized 4-dof PTV contour-based optimization.

Results: The maximum DTA (maxDTA) of the bony anatomy-based autoregistration was 3.2 ± 1.9 mm, with the maximum value of 8.0 mm. The maxDTA of the contour-based optimization was 1.8 ± 1.3 mm, with the maximum value of 5.7 mm. Comparison of Pearson correlation of the compensating parameters between the 2 4-dof optimization algorithms shows that there is a small but statistically significant correlation in y and z (0.236 and 0.300, respectively), whereas there is very weak correlation in x and roll (0.062 and 0.025, respectively).

Conclusions: We find that there is an average improvement of approximately 1 mm in terms of maxDTA on the PTV going from 4-dof bony anatomy-based autoregistration to the 4-dof contour-based optimization. Pearson correlation analysis of the 2 4-dof optimizations suggests that uncertainties due to deformation and inadequate resolution account for much of the compensating parameters, but pitch variation also makes a statistically significant contribution.

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Introduction

Development in conformal radiation therapy techniques, such as intensity modulated radiation therapy, for cancer treatment has increased precision in the delivery of radiation to the target volumes. The enhanced precision allows for improved sparing of normal tissues through a reduction in treatment margins while delivering an increased dose to the prescribed tumor volume. However, setup variation can nullify the advantage of tighter margins. Therefore, precise pretreatment setup verification and correction methods are essential for an optimal conformal radiation therapy treatment.

Helical Tomotherapy uses a linear accelerator mounted on a computed tomography (CT) gantry, thus allowing for CT verification of the daily target position before each treatment. It deploys image guided radiation therapy through comparison of daily pretreatment megavoltage CT (MVCT) scans with kilovoltage CT (kVCT) scans. The setup deviations can be corrected either manually or automatically by matching the registered daily MVCT image to the planning kVCT image by adjusting 3 translational degrees of freedom (dof) and 3 rotational dof (1). However, Tomotherapy can automatically correct only deviations in translational dof and roll. Setup deviations in yaw and pitch are compensated by optimizing the other 4 correctable setup parameters via autoregistration.

The helical Tomotherapy system has 3 modes of rigid image registration: one based on bony anatomy, one based on soft tissue, or using both, depending on the threshold applied to the Hounsfield numbers (2). A previous study using the same set of prostate cancer patients as in this study found the bony anatomy-based autoregistration to be most useful (3). If the MVCT provided better soft-tissue contrast, using the soft-tissue image registration would potentially improve setup accuracy.

Methods and Materials

Even after the physical alignment of the patient's tattoo marks with the wall lasers, setup deviation can still remain owing to the patient's anatomy change since the pretreatment kVCT, distortion in the patient's skin, or couch sag introduced while the couch moves from the setup position to the treatment position. The remaining setup deviation in the patient treatment position can be detected and corrected by the MVCT image registration capability of Tomotherapy. Detected translational shifts and roll can automatically be corrected. However, Tomotherapy hardware is not designed to automatically correct for pitch and yaw. This study compares Tomotherapy's 4-dof bony anatomy-based autoregistration and 4-dof contour-based optimization in compensating for pitch and yaw deviations with the other 4 dof.

The previous study by Kaiser et al (3) collected setup variation data from the image registration for 20 prostate cancer patients using images from week 1 (fractions 1-5) and week 4 (fractions 16-20) of treatment. In this study, we chose to analyze 19 of these patients, one being considered an outlier. The essential geometry and the method of distance-to-agreement (DTA) analysis on the planning target volume (PTV) are shown in Fig. 1. For example, Fig. 1a shows color map of DTA arising from an uncorrected 5° pitch. Figure 1b shows that y and z compensating parameters reduces the maximum DTA (maxDTA).

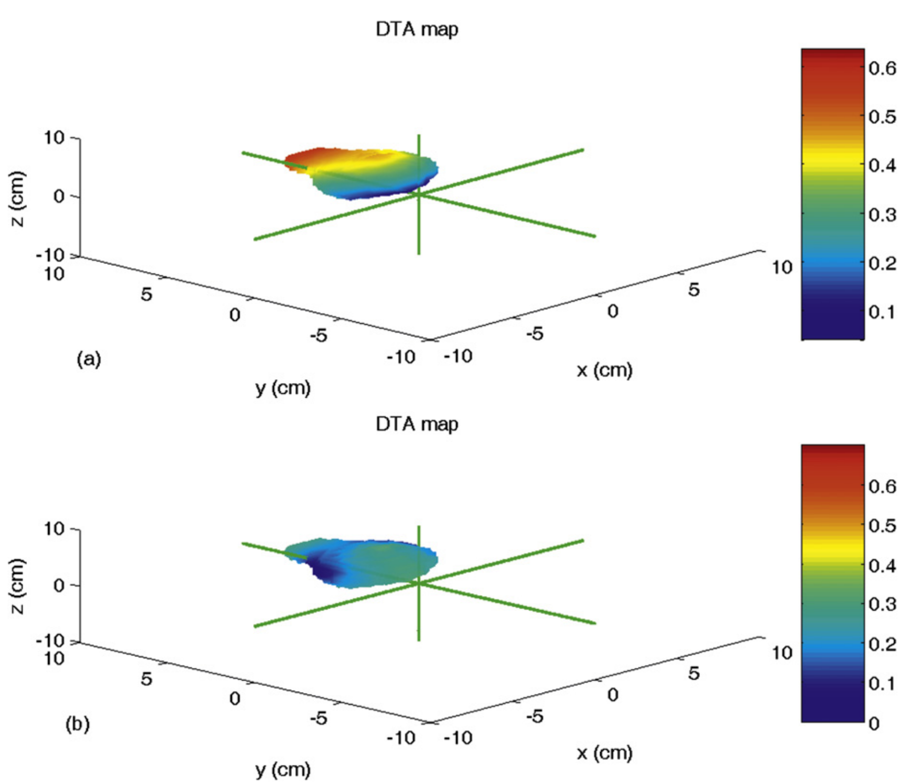

Fig. 1. Distance-to-agreement (DTA) map of prostate cancer planning target volume region of interest with 5° pitch. Color wash indicates distance-to-agreement range from 0 to 0.7 cm. Intersection of the 3 lines in the middle is the isocenter, which is also the center of rotation. Distance-to-agreement (a) uncompensated; (b) compensated by 5-mm y shift and −2-mm z shift.