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Influence of tumor location on the intensity-modulated radiation therapy plan of helical tomotherapy

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ABSTRACT

Given the design of the Helical TomoTherapy device, the patient's central axis is routinely aligned with the machine's rotational axis to prevent the patient's body from colliding with the machine walls. However, for treatment of tumors located away from the patient's central axis, this position may not be optimal as the adequate radiation dose may not reach the affected site. Our study aimed to investigate the influence of tumor location on dose quality and delivery efficiency of tomotherapy plans. A phantom and 15 patients were selected for this study. Two plans, A and B, were implemented for each case. In plan A, the patient's central axis was aligned with the machine's rotational axis, whereas in plan B, the center of the planning target volume (PTV) was aligned with the machine's rotational axis. Both plans were optimized with the same planning parameters, and the dose quality of the plans was evaluated using dosimetrics. The delivery efficiency was determined from delivery time and monitor units (MUs). A paired t-test or nonparametric Wilcoxon signed-rank test was performed for statistical comparison. In the phantom study, the median delivery times were 358 and 336 seconds for plans A and B, respectively, and this difference was significant ($p = 0.005$). In the patient study, the median delivery times were 348 and 317 seconds for plans A and B, respectively, and this difference was also significant ($p = 0.001$). The dose qualities of both plans for each patient were nearly identical. No significant differences were found in the conformal index, heterogeneity index, and mean dose delivered to normal tissue between the plans. Both phantom and patient studies showed that for normal-sized patients, the delivery time reduced as the distance between the PTV and the patient's central axis increased when the PTV center was aligned with the machine axis. In conclusion, aligning the PTV center with the machine's rotational axis by shifting the patient during tomotherapy reduces the delivery time without compromising the dose quality of intensity-modulated radiation therapy.

Introduction

The Helical TomoTherapy device (Accuray Inc., Sunnyvale, CA) is a linear accelerator similar to a computed tomography (CT) scanner but with higher energy delivery characteristics.[1-3] The physical characteristics of this device, such as the rotational fan beam with couch shifting and flattening filter

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free (FFF) photon beams, differ from those of conventional linear accelerators.[4-7] At our institute, the TomoHelical delivery mode and intensity-modulated radiation therapy (IMRT) plan mode are usually used in the clinic. Patients are positioned on the treatment couch similar to how they are positioned during CT simulation for treatment delivery; that is, the patient's central axis is aligned with the rotational axis of the machine regardless of the spatial location of the target. As the transverse profile of the FFF photon beam is approximately of parabolic shape, the output at the beam's central axis is more than that away from it.[8,9] If the center of the planning target volume (PTV) is away from the patient's central axis, the distance between the PTV and beam's axis varies during gantry rotation, and radiation to the PTV is mostly contributed by rays away from the beam's central axis. As the PTV is not always located close to the patient's central axis, it is preferable to align it with the rotational axis of the machine by adjusting the patient's position, thereby maximizing the use of rays at the beam's central axis. Theoretically, this would reduce the delivery time and monitor units (MUs) because of the higher output at the beam's central part.

Currently, there is no evidence of a relationship between the spatial location of PTVs and the delivery efficiency of tomotherapy treatment plans. Further, the influence of the spatial location of PTVs on treatment plan quality when the central axis of the patient is aligned with the rotational axis of the machine is largely unknown. Thus, the present study aims to evaluate the influence of the spatial location of PTVs on the quality and delivery efficiency of the IMRT tomotherapy plan.

Methods

Treatment planning

A phantom and 15 patients were selected for this study.

A CIRS thorax phantom (CIRS Tissue Simulation Technology, Norfolk, VA) was used to simulate a target at different off-axis locations. To exclude the influence of tumor shape on the study results, PTVs were contoured in a uniform shape—a sphere of radius 3 cm. Ten PTVs were contoured at 10 different locations with increasing distances from the phantom's central axis along the lateral axis. For simplicity, only shifts in the lateral direction were simulated in this study. The centers of the PTVs were 1 to 10 cm away from the phantom central axis, with 1-cm spacing along the lateral axis in both the vertical and horizontal directions.

Fifteen patients previously treated with tomotherapy were selected for this study. All patients were immobilized with a customized thermoplastic device that covered the face, thorax, or abdomen and examined using CT with a slice thickness of 3-5 mm depending on the anatomic site of the region of interest. The CT images were transferred to the tomotherapy planning system (Accuray Inc.), and target volumes and organs at risk (OARs) were contoured by physicians. The PTVs were located at various points from the patients' central axes, at distances between 2 and 12 cm. The distance included the distances in the lateral and vertical directions and was calculated using the following formula: $d = \sqrt{d_{lateral}^2 + d_{vertical}^2}$. The diameter of the Helical TomoTherapy bore is 85 cm. The maximum distance the patient was allowed to shift was 12 cm in the lateral direction and 20 to 30 cm in the vertical direction, based on our measurements on the Helical TomoTherapy machine. For a normal-sized patient with a body thickness of 30 cm and width of 38.6 to 48.6 cm, it is unlikely that the patient would collide with the inner surface of the tomotherapy machine if the shifting distance was limited to 12 cm.

Two IMRT treatment plans were generated for each PTV location. Figure 1 illustrates the 2 different phantom/patient positions on the treatment couch. Figure 1A is the position we routinely use in clinical treatment, wherein the central axis of the patient is aligned with the rotational axis of the machine. Figure 1B is the recommended position, in which the center of the PTV is aligned with the rotational

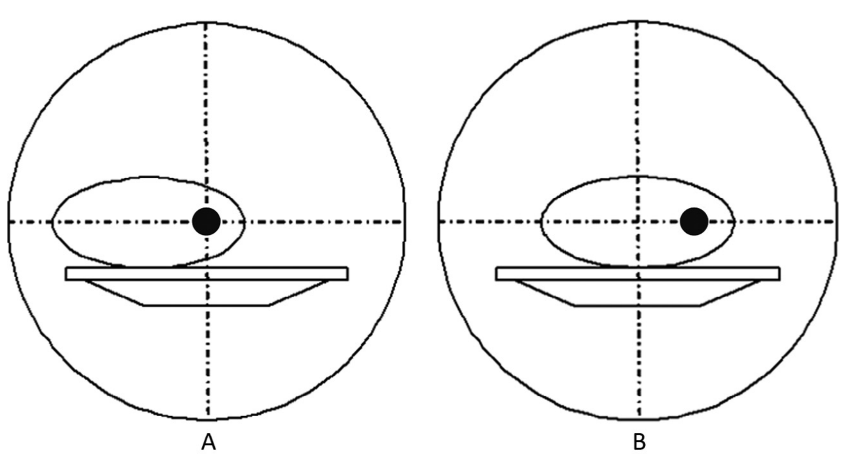

Fig. 1. Two patient setup positions on the treatment couch during tomotherapy. (A) The central axis of the patient is aligned with the central axis of the machine; (B) the center of the PTV is aligned with the central axis of the machine.