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Lung cancer IMRT

An evaluation of planning techniques for stereotactic body radiation therapy in lung tumors☆

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Abstract

***Purpose*: To evaluate four planning techniques for stereotactic body radiation therapy (SBRT) in lung tumors.**

***Methods and materials*: Four SBRT plans were performed for 12 patients with stage I/II non-small-cell lung cancer under the following conditions: (1) conventional margins on free-breathing CT (plan 1), (2) generation of an internal target volume (ITV) using 4DCT with beam delivery under free-breathing conditions (plan 2), (3) gating at end-exhale (plan 3), and (4) gating at end-inhale (plan 4). Planning was performed following the RTOG 0236 protocol with a prescription dose of 54 Gy (3 fractions). For each plan 4D dose was calculated using deformable-image registration.**

***Results*: There was no significant difference in tumor dose delivered by the 4 plans. However, compared with plan 1, plans 2–4 reduced total lung BED by 1.9 ± 1.2, 3.1 ± 1.6 and 3.5 ± 2.1 Gy, reduced mean lung dose by 0.8 ± 0.5, 1.5 ± 0.8, and 1.6 ± 1.0 Gy, reduced V20 by 1.5 ± 1.0%, 2.7 ± 1.4%, and 2.8 ± 1.8%, respectively, with $p < 0.01$. Compared with plan 2, plans 3–4 reduced lung BED by 1.2 ± 1.0 and 1.6 ± 1.5 Gy, reduced mean lung dose by 0.6 ± 0.5 and 0.8 ± 0.7 Gy, reduced V20 by 1.2 ± 1.1% and 1.3 ± 1.5%, respectively, with $p < 0.01$. The differences in lung BED, mean dose and V20 of plan 4 compared with plan 3 were insignificant.**

***Conclusions*: Tumor dose coverage was statistically insignificant between all plans. However, compared with plan 1, plans 2–4 significantly reduced lung doses. Compared with plan 2, plan 3–4 also reduced lung toxicity. The difference in lung doses between plan 3 and plan 4 was not significant.**

Keywords: Image registration; 4D dose; SBRT; Lung tumor

Stereotactic body radiation therapy (SBRT) is emerging as an efficient treatment for Stage I/II medical inoperable and surgically unresectable non-small-cell and metastatic lung cancer [1–12]. Dose escalation and hypofractional dose delivery have the potential to increase patients' survival rates [3] and the probability of local tumor control [4,6,8], while increasing median survival time and long-term progression-free survival [7]. The first dose–response in pulmonary SBRT was reported by Wulf et al. [5]. However, respiration-induced motion can be significant in lung tumors and can result in discrepancies between the planned and delivered doses [13–15]. To more accurately calculate the dose delivered in the case of lung tumors, anatomical motion must be accounted for during treatment planning.

Conventional treatment plans for SBRT of lung tumors are performed on free breathing 3D CT images. Free-breathing CT images are susceptible to motion artifacts, hence, the GTVs delineated on the free-breathing images may inaccurately estimate the position and volume of the tumor and critical structures. Treatment plans using the GTVs delineated on the free-breathing images ignore tumor motion information. Hence, safety margins are added to create the planning target volume (PTV) in order to avoid geometrical misses of the target. Consequently, the volume of healthy tissues irradiated increases.

In contrast, 4D CT-imaging enables the delineation of temporal anatomic translation and deformation information on 3D CT-image sets corresponding to various phases of the respiration cycle. Consequently, the GTVs delineated on the 4D CT images represent more accurately the tumor shape, volume and position [16,17]. The individual target volumes can be combined to form an internal target volume (ITV) [18]. The corresponding PTV was formed by adding a margin that would account for daily setup uncertainties. While both of the above target-definition methods assume that the treatment is delivered under free-breathing conditions, more sophisticated delivery methods such as gating are becoming commonplace in clinical treatments. However, reports describing a planning infrastructure for gated treatments based on 4D CT images are limited [19].

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Irrespective of planning and delivery methods, the dose distribution typically evaluated clinically is a 3D-dose calculated on a single CT image. In reality, organs move due to respiration and the corresponding 4D dose is largely ignored. Several methods have been proposed for 4D-dose calculation [15,20–23]. Lujan et al. [20] and Bortfeld et al. [21] described an approach involving the convolution of the static dose-distribution with the probability distribution function (PDF) of the organ's motion. Craig et al. [22] however, showed that the assumption of ''shift invariance'' in such calculations can produce artifacts in regions with sharp discontinuities such as the patient's surface or in regions with inhomogeneities. Fluence-based methods, in which the fluence is convolved with the PDF of the organ's motion, are not susceptible to such artifacts. Beckham et al. [23] and Chetty et al. [24] calculated 4D dose by convolving the fluence with the PDF. Naqvi and D'Souza developed a stochastic method for calculating the expectation 4D-dose distribution from a large number of treatment fractions in which the isocenter traces the trajectory of the organ [15]. However, none of the above approaches considered anatomical deformation.

Recently, more advanced techniques have been used for 4D-dose calculation [12,19,25,26], and are based on the elastic registration of the 4D-CT images. Elastic image registration tracks the displacement of each voxel during a respiratory cycle. The dose summed along the trajectory of each voxel provides a more accurate estimate of 4D dose. This method explicitly takes into account the relative anatomic changes in shape, volume, position, and density during normal respiration. Rietzel et al. calculated dose for patients with thoracic and hepatocellular tumors by performing B-splines based deformable image registration using an open source software package [25]. Guerrero et al. developed a 3D optical flow-based elastic registration algorithm and calculated the 4D-dose distribution using a computer-generated 4D thoracic phantom [26]. However, this study was limited to phantom images. Flampouri et al. estimated the dose delivered from IMRT to lung tumor patients based on elastic image registration of 4D CT [19]. However, these studies considered only conventional fractionation schemes. Guckenberger et al. investigated the influence of tumor motion on the dose delivery of lung SBRT [12]. However, they studied only one delivery scenario: free breathing with ITV-based treatment planning.

Since hypofractionation and more sophisticated delivery methods (such as gating) are being increasingly considered for early-stage lung tumors, it becomes necessary to calculate more accurately estimates of the dose in the presence of respiration-induced tumor motion. The Radiation Therapy Oncology Group (RTOG) recently concluded a national trial for hypofractionated delivery in medically inoperable and surgically unresectable lung tumors (protocol # RTOG 0236). At our institution, a similar trial has been underway. In this work, we retrospectively compared the 4D dose calculated under four different treatment planning and delivery scenarios for SBRT treatments of lung tumors. The four treatment planning and delivery techniques were evaluated by comparing their corresponding composite 4D-dose distributions.

Methods and materials

Twelve lung cancer patients who underwent hypofractionated radiotherapy at our institution were retrospectively selected for this study. Each patient underwent a 4D-simulation using the Brilliance multi-slice CT scanner (Philips Medical Systems, Cleveland, OH) with the respiration phase inferred using an infrared marker/camera system (RPM system, Varian Medical Systems, Palo Alto, CA). Each 4D CT data set comprised ten 3D CT images corresponding to equally spaced phases in the respiratory cycle.

For each patient, we performed treatment planning according to the guidelines in the RTOG 0236 protocol [27]. The prescription dose, however, at our institution (using our institutional protocol) was set to 18 Gy/fraction for a total of 3 fractions. We will briefly summarize the planning parameters and constraints here. All plans were normalized such that 54 Gy was prescribed to the 85% isodose line. The maximum point dose to the heart, trachea and ipsilateral bronchus was required to be less than 30 Gy; the maximum point doses to the spinal cord, esophagus, and ipsilateral brachial plexus were required to be less than 18, 27 and 24 Gy, respectively; V20 of the total lung (ipsilateral and contralateral lung) volume was required to be less than 15%. All of these requirements and constraints were satisfied for all of the plans.

The monitor units (MU) were determined by assuming homogeneous patient geometry (as required by RTOG 0236). However, the final dose-calculations including the effective 4D-dose calculations described below were performed using heterogeneity corrections. This was done by first recording the MUs of each beam from the original plans performed with homogeneous assumption. The plan parameters were then copied to each individual 4D-CT images to recalculate the dose with heterogeneity correction using the MUs obtained from the homogeneous plan. A convolution/superposition algorithm implemented by the Pinnacle^3 planning system (Philips Medical Systems, Cleveland, OH) was used for dose calculation. Convolution/superposition algorithm has been shown to be in agreement with Monte-Carlo (MC) simulation for dose calculation in heterogeneous media [28–30].

Four treatment plans were generated for each patient case. Each treatment plan simulated a different planning and delivery scenario. Table 1 summarizes these four SBRT plans. In plan 1, a 5 mm margin in the anterior–posterior (AP) and medial–lateral (ML) directions and a 10 mm margin in the cranio–caudal (CC) direction were added to the GTV contoured on the free-breathing (FB) CT image set to create the PTV. In plan 2, the GTV was delineated on each of the 3D-CT data sets in the 4D CT. These GTV volumes were combined to yield an ITV. A uniform 5 mm margin was then added to the ITV to form the PTV, which was then imported onto the FB CT. In both, plans 1 and 2, planning was performed on the FB CT. However, unlike plan 1, plan 2 takes into account respiration-induced tumor motion. These two plans correspond to radiation delivery under free-breathing conditions. Plans 3 and 4 were generated to simulate gating at end-exhale and end-inhale, respectively. Phase-based gating was assumed with a 30% duty cycle. In plan 3, the GTVs in the 4D-CT data set that fell within the 30% duty