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Physics Contribution

Dosimetric Impact of Breathing Motion in Lung Stereotactic Body Radiotherapy Treatment Using Image-Modulated Radiotherapy and Volumetric Modulated Arc Therapy

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Summary

This study investigated the impact of tumor motion on the calculation of 4D dose distribution of the gross tumor volume (GTV) in lung SBRT treatment using fixed field IMRT and VMAT. The results show that both VMAT and IMRT plans experienced negligible interplay effects between MLC sequence and tumor motion. The dose to the GTV was slightly decreased on average (1% of prescription) in the 4D calculation compared with the 3D calculation.

Purpose: The objective of this study was to investigate the influence of tumor motion on dose delivery in stereotactic body radiotherapy (SBRT) for lung cancer, using fixed field intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT).

Methods and Materials: For each of 10 patients with stage I/II non-small-cell pulmonary tumors, a respiration-correlated four-dimensional computed tomography (4DCT) study was carried out. The internal target volume was delineated on the maximum intensity projection CT, which was reconstructed from the 4DCT dataset. A 5-mm margin was used for generation of the planning target volume. VMAT and five-field IMRT plans were generated using Pinnacle^3 SmartArc and direct machine parameter optimization, respectively. All plans were generated for an Elekta Synergy linear accelerator using 6-MV photons. Simulation was performed to study the interplay between multileaf collimator (MLC) sequences and target movement during the delivery of VMAT and IMRT. For each plan, 4D dose was calculated using deformable image registration of the 4DCT images. Target volume coverage and doses to critical structures calculated using 4D methodology were compared with those calculated using 3D methodology.

Results: For all patients included in this study, the interplay effect was found to present limited impact (less than 1% of prescription) on the target dose distribution, especially for SBRT, in which fewer fractions (three fractions) are delivered. Dose to the gross tumor volume (GTV) was, on average, slightly decreased (1% of prescription) in the 4D calculation compared with the 3D calculation. The motion impact on target dose homogeneity was patient-dependent and relatively small.

Conclusions: Both VMAT and IMRT plans experienced negligible interplay effects between MLC sequence and tumor motion. For the most part, the 3D doses to the GTV and critical structures provided good approximations of the 4D dose calculations. © 2012 Elsevier Inc.

Keywords: IMRT, Nonrigid deformable image registration, Respiratory motion, Stereotactic body radiotherapy, Volumetric modulated arc therapy

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Introduction

Volumetric modulated arc therapy (VMAT) is a relatively new treatment technique that can reduce treatment time while it produces dose distributions that are comparable to or improved relative to those of fixed field intensity-modulated radiotherapy (IMRT) (1–6). Recent studies (7, 8) have shown that VMAT allows delivery of hypofractionated doses much faster than conventional stereotactic body radiation therapy (SBRT) using three-dimensional (3D) conformal radiotherapy, with the additional advantage that the plans are more conformal than those of conventional SBRT.

One concern with the use of VMAT and IMRT for lung treatment is whether tumor motion will lead to significant underdosage of portions of the tumor volume. Compared with 3D conformal RT, there is complicated interplay between the multileaf collimator (MLC) motion and tumor motion in IMRT. In previous studies (9–12), the effect of intrafraction motion on IMRT dose delivery was investigated based on the probability density function modeling of the tumor motion. The authors concluded that interplay between organ motion and leaf motion is not dosimetrically significant when the dose is delivered over multiple (~30) fractions. However, dose averaging may not work well for SBRT, where fewer (3 ~5) fractions are used. This may raise concern about using IMRT or VMAT for SBRT for lung tumor. Seco *et al.* (13) studied organ motion effects on IMRT with segments of few monitor units (MUs). Their results suggested that for hypofractionation regimens where higher doses are delivered per fraction, there are likely more MUs per segment, which will cause a lower overall dose error; however, they also pointed out that for hypofractionation, probability density function modeling of tumor motion in IMRT may not be adequate.

With the use of 4D respiration-correlated computed tomography (CT) (14–16), there have been 4D treatment planning studies (17–19) that investigated the impact of tumor motion on the calculation of 4D dose distributions. In those studies, however, the interplay between dynamic beam delivery and organ motion was not explicitly included. To simplify the 4D dose calculation procedure, it was assumed in those studies that the MUs of each segment in an IMRT plan were equally distributed to all the breathing phases.

As an arc-based IMRT technique, VMAT allows the radiation dose to be delivered in a single gantry rotation of up to 360°. During VMAT delivery, the leaf positions, gantry speed, and dose rate change continuously while the gantry is rotating. Compared to fixed field IMRT, the situation becomes more complicated when the intrafraction respiratory motion is considered. The purpose of this study was to investigate the impact of tumor motion on the calculation of 4D dose distribution of the gross tumor volume (GTV) in lung SBRT using fixed field IMRT and VMAT. The interplay between MLC leaf sequence, jaw movement, gantry rotation, and target movement during free-breathing treatment using VMAT was simulated. We compared the interplay effect between MLC segments and tumor motion during IMRT and VMAT delivery in both conventional treatment of 30 fractions and SBRT of 3 fractions. The dose-volume results for the target and critical structures are presented, and related clinical implications are discussed.

Methods and Materials

Patient selection

Ten patients treated with SBRT for lung cancer were included in this retrospective study. All patients had stage I/II non-small-cell lung cancer. Six of the patients had tumors in their right lung, and four patients had tumors in the left lung. Table 1 lists the tumor position, volume, and motion extent for all patients. Tumor motion amplitudes were determined using the maximum 3D displacement of the center of mass of the tumor during the breathing cycle.

Image acquisition

Patients were immobilized with a vacuum cushion and cover sheet (BodyFIX; Medical Intelligence, Schwabmuenchen, Germany) to limit voluntary and involuntary motions. An abdominal compressor was used if the mean tumor motion was larger than 10 mm. Patients received minimal training to ensure regular respiration. All patients were imaged using 4D CT with 8-slice positron emission tomography (PET)/CT scanner (GE Medical Systems, Waukesha, WI) with breathing phases inferred from an infrared marker and camera system (RPM system; Varian Medical Systems, Palo Alto, CA). Each 4D CT image set was composed of 10 3D CT images corresponding to equally spaced phases of a breathing cycle. Images with a slice thickness of 3 mm were obtained.

Treatment planning

GTV was delineated on each respiratory study by using the "lung window" setting by a radiation oncologist. Critical structures, including but not limited to ipsilateral and contralateral lungs, spinal cord, heart, and esophagus, were outlined. Internal target volume was determined based on the maximum intensity projection 4DCT dataset. Internal target volume was expanded by 5 mm to account for daily set-up variations to create a planning target volume (PTV). The PTV was enclosed at the minimum by the 95% isodose line with a dose prescription of 30 × 2 Gy (or 3 × 20 Gy for SBRT). Inhomogeneity corrections were applied during dose calculations.

Fixed field IMRT and VMAT plans were generated for an Elekta Synergy linear accelerator (LINAC) using 6-MV photons. The LINAC is equipped with PreciseBeam (Elekta) VMAT LINAC control system and a conventional 80-leaf MLC (1-cm-wide leaf at isocenter). VMAT plans were generated using Pinnacle^3 SmartArc inverse planning module, and a partial arc was used for each tumor. For comparison purposes, five-field (step-and-shoot) IMRT plans were also created using direct machine parameter optimization in the Pinnacle^3 treatment planning system for each case. The same optimization objectives and penalties were used for VMAT and IMRT plans.

3D dose calculations

Plan doses were calculated based on end-of-exhalation (EOE; 50% phase) CT data using the collapsed cone convolution