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Dosimetric comparison of two arc-based stereotactic body radiotherapy techniques for early-stage lung cancer

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ABSTRACT

To compare the dosimetric and delivery characteristics of two arc-based stereotactic body radiotherapy (SBRT) techniques for early-stage lung cancer treatment. SBRT treatment plans for lung tumors of different sizes and locations were designed using a single-isocenter multisegment dynamic conformal arc technique (SiMs-arc) and a volumetric modulated arc therapy technique (RapidArc) for 5 representative patients treated previously with lung SBRT. The SiMs-arc plans were generated with the isocenter located in the geometric center of patient's axial plane (which allows for collision-free gantry rotation around the patient) and 6 contiguous 60° arc segments spanning from 1° to 359°. 2 RapidArc plans, one using the same arc geometry as the SiMs-arc and the other using typical partial arcs (210°) with the isocenter inside planning target volume (PTV), were generated for each corresponding SiMs-arc plan. All plans were generated using the Varian Eclipse treatment planning system (V10.0) and were normalized with PTV V_{100} to 95%. PTV coverage, dose to organs at risk, and total monitor units (MUs) were then compared and analyzed. For PTV coverage, the RapidArc plans generally produced higher PTV D_{99} (by 1.0% to 3.3%) and higher minimum dose (by 2.7% to 12.7%), better PTV conformality index (by 1% to 8%), and less volume of 50% dose outside 2 cm from PTV (by 0 to 20.8 cm^3) than the corresponding SiMs-arc plans. For normal tissues, no significant dose differences were observed for the lungs, trachea, chest wall, and heart; RapidArc using partial arcs produced lowest maximum dose to spinal cord. For dose delivery, the RapidArc plans typically required 50% to 90% more MUs than SiMs-arc plans to deliver the same prescribed dose. The additional intensity modulation afforded by variable gantry speed and dose rate and by overlapping arcs enabled RapidArc plans to produce dosimetrically improved plans for lung SBRT, but required more MUs (by a factor $>$ 1.5) to deliver. The dosimetric improvements, most notably in PTV minimum dose and in dose conformality for irregularly shaped PTVs, may outweigh the increased MUs in using RapidArc. For small and peripherally located tumors, SiMs-arc produces comparable dosimetric quality and could be more efficient in both treatment planning and dose delivery.

Introduction

Stereotactic body radiation therapy (SBRT) has proven to be an effective treatment modality for medically inoperable early-stage lung cancers in selected patients.[1-3] It is being used by more and more radiation therapy clinics in the management of selected tumors in the lungs and at other disease sites.[4] The primary dosimetric goal of SBRT is to design a treatment that can concentrate a large amount of dose precisely to the target volume with fast dose falloff in normal tissue.[4,5] Earlier implementation of SBRT used multiple ($>$ 10) noncoplanar photon beams (with or without intensity modulation) focused at the target volume. For noncentrally located tumors, one has to be vigilant about potential collision of the collimator with the treatment couch or patient for certain beam configurations. One also has to carefully evaluate the beam weights, especially for those beams traversing shorter skin-to-target distances, to avoid incidental skin toxicities.[6] To alleviate these concerns, a single-isocenter multisegment dynamic conformal arc technique (SiMs-arc) has been introduced for lung SBRT.[7] The

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SiMs-arc technique is capable of producing equal or better quality plans compared with noncoplanar fixed beam techniques.[8] In addition, it improves the efficiency and consistency of SBRT treatment planning and dose delivery. This technique has been used as a primary technique in our department before the clinical implementation of volumetric modulated arc therapy (VMAT)[9] and by others who do not have access to the VMAT technology.[10]

Although SiMs-arc does not require additional capital funding and human resources to set up and operate and is logistically easy to set up for clinics without access to advanced VMAT technology, VMAT does offer additional degrees of freedom (gantry speed and dose rate) for intensity modulation and dosimetric design. It is therefore interesting from both scientific and economic (accessibility) points of view to quantify the dosimetric differences of the 2 techniques as well as their delivery efficiency. This information would be scientifically interesting for dosimetrists and physicists who have access to both VMAT and SiMs-arc techniques and, in particular, clinically valuable for those who do not have access to VMAT but would like to start a SBRT program for lung cancer. In the following, we report the results of a systematic study comparing SiMs-arc with VMAT for lung SBRT.

Methods and Materials

Patient selection

A total of 5 lung SBRT patients previously treated in our department were selected for this study. The cases were selected to represent a range of planning target volume (PTV) sizes (from 18.2 to 95 cm^3) and tumor locations (left/right lung and upper/lower lobe) as typically encountered in lung SBRT. Table 1 summarizes the relevant information.

Treatment planning

All patients were immobilized with both arms down in a CIVCO full-body Vac-Lok cushion (CIVCO Medical Solutions, Coralville, IA) during simulation and treatment delivery. For each patient, a 4-dimensional computed tomography (4DCT) scan was acquired with Varian real-time position management system, v1.7.5 (Varian Medical System, Palo Alto, CA) on a 16-slice GE LightSpeed CT scanner (GE Healthcare, Waukesha, WI) with 2.5-mm slice thickness during CT simulation. The internal target volume was contoured by physicians based on the maximum intensity projection of 4DCT as well as the tumor appearance visualized in the movie loop of 4D phase images. PTV was generated by adding a uniform margin of 7 mm to the internal target volume. All critical structures including lungs, spinal cord, brachial plexus, esophagus, heart/great vessels, tracheobronchial tree, skin, and chest wall were contoured for those cases where these structures lay within 3 cm of the PTV. Treatment plans for both the SiMs-arc and RapidArc were designed using the Varian Eclipse treatment planning system, version 10.0 (Varian Medical System, Palo Alto, CA) using 6-MV photon beams. Of the 5 patients, 3 were planned using high-definition multileaf collimator (MLC) with 2.5-mm central leaves, and the other 2 patients were planned using Millennium MLC with 5.0-mm central leaves. Dose calculation was performed on the average intensity projection CT (reconstructed from the 4DCT) using the Anisotropic Analytical Algorithm, version 10.0.28 with tissue heterogeneity correction and a 2.5-mm dose calculation grid. All patients received a total dose of 54 Gy given in 3 fractions.

Details of treatment planning with the SiMs-arc technique have been reported earlier.[7,8] Briefly, the SiMs-arc technique uses primarily dynamic beam-aperture modulation for generating a conformal dose distribution. It consists of six 60° arc segments spanning from 1° to 359°, with the isocenter located in the geometric center of the patient's axial plane (Fig. 1, Left). By placing the isocenter in the geometric center of the patient's axial plane (usually outside the PTV), it allows the gantry to rotate freely around the patient without colliding into the couch or patient. The dynamic MLC apertures of each arc segment were determined primarily by the outline of PTV seen in the beam's eye view with the following adjustments to achieve a desired dose falloff in the superior and inferior directions: a superior and inferior margin of 7.5 mm was added to PTV for the contralateral lateral arc relative to the tumor site and the next 2 alternating arcs; a superior and inferior margin of 2.5 mm was added for the ipsilateral lateral arc relative to the tumor site and the next 2 alternating arcs. Zero margins were used for all other dimensions (laterally, anteriorly, and posteriorly). Auto "fit MLC to Structure" tool was used to shape the dynamic MLC apertures of each arc segment. The field weightings for each arc segment were manually adjusted if needed to achieve a clinically acceptable SBRT plan for each case. Treatment planning and dose delivery for the SiMs-arc technique is much simplified compared with traditional noncoplanar fixed beam techniques.[1,2]

In addition to dynamic beam-aperture modulation, RapidArc also uses gantry speed and dose rate modulation in the generation of a desired dose distribution. Coupled with inverse planning, RapidArc is expected to be more versatile than the SiMs-arc technique in generating more complex dose distributions. To quantify the dosimetric effect of the additional gantry speed and dose rate modulations, 2 RapidArc plans were generated for each patient. The first plan used the same arc geometry as the SiMs-arc setup (Fig. 1, Left) so that a dosimetric comparison with the SiMs-arc technique provides a direct measure of the dosimetric contributions of the additional gantry speed and dose rate modulations. The second plan used partial arcs with isocenter situated inside the PTV (as in common RapidArc applications) (Fig. 1, Right). The use of partial arcs (ranging from 180° to 220°) enables the placement of treatment isocenter inside the PTV without running into couch/patient collisions. A comparison of this plan with SiMs-arc plan would reveal if the additional gantry speed and dose rate modulations can be used to offset the lack of radiation beams from the absent gantry angles. As our goal is to perform a

Table 1
General patient information

Patient	Sex	Age	PTV (cm^3)	Stage	Tumor location
1	Male	78	28.5	T1aN0M0	Right upper lobe
2	Male	62	18.2	T1aN0	Left upper lobe
3	Female	47	19.3		Right medial lobe
4	Male	79	95	T2bN0M0	Right upper lobe
5	Female	55	64	T2N0M1	Left lower lobe

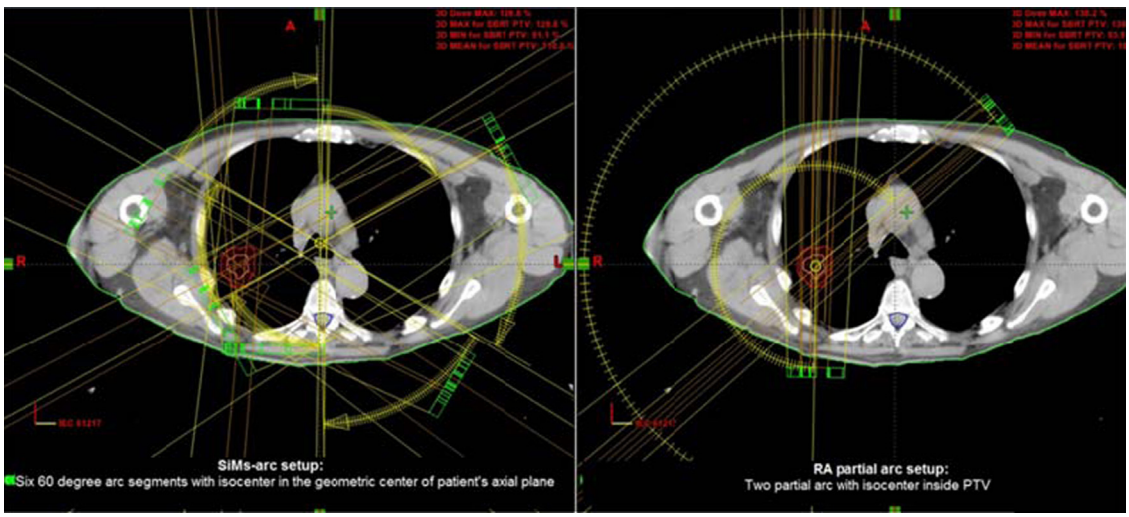

Fig. 1. Arc geometry comparison: (left panel) the arc setup for Sims-arc and for the full-arc RapidArc setup, and (right panel) one partial-arc setup for RapidArc. (Color version of figure is available online.)