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Fast Arc Delivery for Stereotactic Body Radiotherapy of Vertebral and Lung Tumors

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Summary

For 10 patients with peripheral lung tumors and 10 with vertebral metastases, stereotactic body radiotherapy RapidArc plans generated using 10-MV flattening filter-free beams were compared with plans using 6-MV flattened beams. This study showed that plan quality was similar between the two techniques, but flattening filter-free beams reduced the delivery time, allowing fraction doses of up to 18 Gy to be delivered within 4 min. Dosimetry revealed excellent agreement between measured and calculated dose distributions.

Purpose: Flattening filter–free (FFF) beams with higher dose rates and faster delivery are now clinically available. The purpose of this planning study was to compare optimized non-FFF and FFF RapidArc plans for stereotactic body radiotherapy (SBRT) and to validate the accuracy of fast arc delivery.

Methods and Material: Ten patients with peripheral lung tumors and 10 with vertebral metastases were planned using RapidArc with a flattened 6-MV photon beam and a 10-MV FFF beam for fraction doses of 7.5–18 Gy. Dosimetry of the target and organs at risk (OAR), number of monitor units (MU), and beam delivery times were assessed. GafChromic EBT2 film measurements of FFF plans were performed to compare calculated and delivered dose distributions.

Results: No major dosimetric differences were seen between the two delivery techniques. For lung SBRT plans, conformity indices and OAR doses were similar, although the average MU required were higher with FFF plans. For vertebral SBRT, FFF plans provided comparable PTV coverage, with no significant differences in OAR doses. Average beam delivery times were reduced by a factor of up to 2.5, with all FFF fractions deliverable within 4 min. Measured FFF plans showed high agreement with calculated plans, with more than 99% of the area within the region of interest fulfilling the acceptance criterion.

Conclusion: The higher dose rate of FFF RapidArc reduces delivery times significantly, without compromising plan quality or accuracy of dose delivery.

Keywords: RapidArc, Flattening filter free, SBRT, NSCLC, Vertebral metastases

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Conflict of interest: The VU Medical Center has research collaborations with Varian Medical Systems and Brainlab.

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Introduction

Stereotactic body radiotherapy (SBRT) is an established treatment approach for both curative and palliative indications. High control rates with minimal toxicity have been reported by studies in early-stage non-small-cell lung cancer (NSCLC) (1) and vertebral metastases (2, 3). These excellent outcomes are achieved by precise delivery of high radiation doses to the target in a single or a few fractions, while sparing the surrounding normal tissues. To achieve such high dose conformity and steep dose fall-off outside the lesion, SBRT for lung tumors is commonly delivered using several coplanar and noncoplanar static beams, or volumetric modulated arc therapy. Stereotactic body radiotherapy for vertebral metastases is often delivered using seven or more static intensity-modulated radiotherapy beams or volumetric modulated arc therapy with multiple arcs (4).

Stereotactic body radiotherapy delivery times are often prolonged owing to the high dose per fraction, limited dose rate, use of multiple treatment beams, and intensity-modulated radiotherapy delivery. For typical SBRT treatments, the monitor units (MU) required for a fraction dose in excess of 10 Gy are in the range of 2000−10,000 MU. Total setup and treatment times, inclusive of all time spent with patient on the couch for SBRT, can extend up to 90 min (2) and 60 min (5) for SBRT of vertebral metastases and NSCLC, respectively. Extended treatment times can increase the risk of tumor displacement during delivery (6) and necessitate extra imaging for position verification. Therefore, it is logical to investigate faster delivery as one component of reducing overall treatment time and facilitating treatment accuracy.

Different volumetric modulated arc therapy approaches have been used to deliver SBRT (4, 7). One of these is RapidArc (Varian Medical Systems, Palo Alto, CA), which permits efficient delivery of highly conformal dose distributions (8). However, in particular for high fraction doses, the minimum treatment time may be substantially influenced by the maximum dose rate. The dose rate of a beam can be increased by removal of the flattening filter. The resulting flattening filter−free (FFF) beams have a cone-shaped dose profile (9) and up to a fourfold higher dose rate in the center of the beam. The use of inverse planning that takes into account the basic beam profile facilitates the use of FFF beams. Flattening filter−free delivery techniques have been reported for three-dimensional conformal radiotherapy (10) and intensity-modulated radiotherapy (11).

In this retrospective study, we evaluated plan quality and beam delivery time for RapidArc plans for SBRT of NSCLC and vertebral metastases generated using an FFF beam, and compared them with plans generated using a standard flattened beam. To validate the accuracy of fast arc delivery for clinical use, several FFF plans were measured using film dosimetry.

Methods and Materials

Ten patients with Stage I NSCLC and 10 patients with vertebral metastases, all of whom had undergone SBRT at our center, were replanned for this study. One patient each with a vertebral metastasis and a lung tumor were clinically treated using FFF plans, whereas all others were treated using flattened beams. All plans were created using the Eclipse treatment-planning system (version 8.9.08; Varian Medical Systems), and dose calculations were carried out using the anisotropic analytical algorithm (AAA) with a grid resolution of 2.5 mm, taking into account heterogeneity correction. The collimator angles for all arcs were between 30° and 45°.

The mean planning target volume (PTV) for NSCLC patients was 58.2 cm^3 (range, 8.9−153.4 cm^3). For patients with vertebral metastases, the mean PTV was 119 cm^3 (range, 34.13−225.9 cm^3), and mean PTV length was 7.3 cm (range, 2.9−11.5 cm). Two RapidArc plans were generated for each case, one using a flattened beam (FF) and the other an FFF beam. Clinical FF plans using 6-MV flattened photon beams were delivered on a Novalis Tx accelerator (Varian Medical Systems, Palo Alto, CA), equipped with a high-definition multileaf collimator (HD-MLC, spatial resolution of 2.5 mm at isocenter) at a maximum dose rate of 1000 MU/min. The FFF plans using 10-MV FFF beams were delivered on a TrueBeam accelerator (Varian Medical Systems, Palo Alto, CA), equipped with a millennium MLC (spatial resolution of 5 mm at isocenter) using a maximum dose rate on the central beam axis of 2400 MU/min. The dosimetric leaf gaps and transmission factor used in the treatment-planning system for the millennium MLC (FFF beams) and the HD-MLC (FF beams) were 1.37 mm and 1.4% and 0.9 mm and 1.0%, respectively.

Imaging and target definition

For lung cases, a PTV was created by adding a margin of 5 mm to the internal target volume (ITV), which encompassed all motion observed on four-dimensional CT scan (8). Organs at risk (OAR) were delineated on the average intensity projection CT, including the contralateral lung, spinal cord, esophagus, heart, trachea, and chest wall.

For vertebral cases, the gross tumor volume and clinical target volume were delineated, and the PTV was generated by adding a 3-mm margin. The spinal cord, cauda equine, or thecal sac (referred to collectively as "spinal cord") was delineated on a planning CT scan using MRI fusion (12). Depending on the location of the PTV and the vertebrae, additional OAR included liver, lungs, esophagus, bowel, skin, kidneys, ureters, and nerve roots or nerve plexus. To account for various sources of positional uncertainty during image-guided vertebral SBRT, a spinal cord planning at risk volume (PRV) was created by adding a 2-mm margin to the spinal cord (13).

Treatment-planning technique

Lung SBRT was delivered using a "risk adapted" fractionation scheme of either 3 fractions of 18 Gy ($n = 4$), 5 fractions of 11 Gy ($n = 3$), or 8 fractions of 7.5 Gy ($n = 3$), determined by T stage and proximity to the adjacent normal tissues (1). All plans were normalized such that the prescription dose corresponded to the 80% isodose. Details of treatment planning have been reported previously (8). Planning objectives for the PTV required that 95% of the PTV received at least the nominal fraction dose and that the maximum dose was 1105−140% of the prescription dose (14). All plans required a clockwise and a counterclockwise arc for each fraction. The two different arcs were optimized sequentially for 50% of the dose, whereby the second arc referred to the calculated dose distribution using AAA of the first arc and compensated for any under- or overdosage in the PTV due to shortcomings in accuracy of the optimizer calculation algorithm in low-density media (8). The FFF plans were optimized using the same field settings and optimization constraints.