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PHYSICS CONTRIBUTION

FEASIBILITY OF SINGLE-ISOCENTER VOLUMETRIC MODULATED ARC RADIOSURGERY FOR TREATMENT OF MULTIPLE BRAIN METASTASES

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Purpose: To evaluate the relative plan quality of single-isocenter vs. multi-isocenter volumetric modulated arc therapy (VMAT) for radiosurgical treatment of multiple central nervous system metastases.
Methods and Materials: VMAT plans were created using RapidArc technology for treatment of simulated patients with three brain metastases. The plans consisted of single-arc/single-isocenter, triple-arc (noncoplanar)/single-isocenter, and triple-arc (coplanar)/triple-isocenter configurations. All VMAT plans were normalized to deliver 100% of the 20-Gy prescription dose to all lesions. The plans were evaluated by calculation of Paddick and Radiation Therapy Oncology Group conformity index scores, Paddick gradient index scores, and 12-Gy isodose volumes.
Results: All plans were judged clinically acceptable, but differences were observed in the dosimetric parameters, with the use of multiple noncoplanar arcs showing small improvements in the conformity indexes compared with the single-arc/single-isocenter and triple-arc (coplanar)/triple-isocenter plans. Multiple arc plans (triple-arc [noncoplanar]/single-isocenter and triple-arc [coplanar]/triple-isocenter) showed smaller 12-Gy isodose volumes in scenarios involving three metastases spaced closely together, with only small differences noted among all plans involving lesions spaced further apart.
Conclusion: Our initial results suggest that single-isocenter VMAT plans can be used to deliver conformity equivalent to that of multiple isocenter VMAT techniques. For targets that are closely spaced, multiple noncoplanar single-isocenter arcs might be required. VMAT radiosurgery for multiple targets using a single isocenter can be efficiently delivered, requiring less than one-half the beam time required for multiple isocenter set ups. VMAT radiosurgery will likely replace multi-isocenter techniques for linear accelerator-based treatment of multiple targets. © 2010 Elsevier Inc.

Brain, metastases, volumetric modulated arc therapy, VMAT, radiosurgery, RapidArc.

INTRODUCTION

Volumetric modulated arc therapy (VMAT) is a novel plan optimization and treatment delivery platform in which radiation can be delivered efficiently and accurately in ≥1 dynamically modulated arcs (1). VMAT achieves conformal dose distributions by simultaneously varying the speed of the gantry rotation, the dose rate of the linear accelerator, and the multileaf collimator (MLC) aperture shape. It is similar to tomotherapy in that a full 360° of beam directions are available for optimization; however, it differs in that the entire dose volume is irradiated during each source rotation. Rapid Arc (Varian Medical Systems, Palo Alto, CA) is a commercial implementation of VMAT based on the work of Otto (1).

Recent treatment planning studies using VMAT have reported highly conformal dose distributions, a rapid treatment time, and relatively low monitor units required to deliver treatment for prostate (2) and cervical cancer (3), as well as benign intracranial tumors (4). Although the initial results have been promising, researchers have reported the need for additional investigation of VMAT treatment plans for other tumor sites (2–4). The published data on VMAT have presented analyses of single or coplanar arcs only. Cozzi *et al.* (3) and Fogliata *et al.* (4) specifically commented on the need for a future assessment of the role of noncoplanar arcs and the necessary number of modulated arcs to achieve the ‘‘ideal’’ dose distribution for different tumor site scenarios.

The role of stereotactic radiosurgery (SRS) with and without whole brain radiotherapy (WBRT) in the initial treatment of newly diagnosed brain metastases has been evaluated by two recent randomized clinical trials (5, 6). Published data

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by Andrews *et al*. (5) showed significantly greater stability of function at 6 months in patients undergoing SRS as a part of their initial treatment. The local control rate at 1 year improved from 71% to 82% with the addition of SRS. Many clinicians have used the results of such research to justify the use of SRS in the initial treatment of patients with one to three brain metastases with or without WBRT. In addition to up-front therapy for newly diagnosed brain metastases, SRS currently plays a role as an important treatment modality for patients with recurrent or progressive disease, particularly those patients without a burden of extracranial tumor that could limit the survival advantage of a brain-specific treatment such as radiosurgery.

Traditionally, linear accelerator-based SRS techniques for the treatment of multiple central nervous system metastases have used a multi-isocenter set up, aligning each isocenter around the individual metastatic lesions. The treatment duration for a multi-isocenter technique is roughly proportional to the number of lesions treated, typically ranging from 20 min for a single lesion to >1 h for multiple lesions. Although gamma knife SRS (GKSRS) is often use at our institution as initial or salvage treatment for patients with metastatic brain lesions, the research team wished to evaluate the clinical feasibility of using a single-isocenter linear accelerator-based VMAT radiosurgery approach because of its potential strengths in conformity, treatment time, and patient/provider convenience. The clinical role, case selection properties, and complementary nature of linear accelerator-based radiosurgery in a facility that also uses GKSRS has previously been reported (7); however, the VMAT-based treatment platform emphasizes the clinical use of such an approach. Therefore, the goal of the present study was to compare single- and multi-isocenter VMAT plans for patients with multiple brain metastases to evaluate the possible clinical applications of this technique. More specifically, we wished to determine whether a single-isocenter VMAT approach for treatment of brain metastases was feasible and/or dosimetrically similar to multi-isocenter VMAT and GKSRS plans. Our hypothesis was that as the plan complexity increased with larger numbers of tumors, a clinically significant dosimetric advantage would be realized in using multiple isocenters or multiple noncoplanar arcs. However, the use of multiple isocenters or multiple arcs could prolong the treatment time and negate the delivery efficiency of VMAT.

METHODS AND MATERIALS

Simulated patients: three brain metastases

A treatment planning computed tomography scan of a brain patient was used to create four simulated patient cases. For each simulated patient, three phantom brain metastases of varying diameters were contoured onto the brain computed tomography scan to produce a range of patient tumor burden scenarios. Each patient tumor burden consisted of three spherical brain tumors of varying diameters: 10, 15, and 20 mm. The patient characteristics differed by two factors: the distance between the brain lesions (3 cm vs. 6 cm from the outside edge of each tumor) and the location of the lesions with regard to a common axial plane (all tumors in the same plane vs. all tumors in different planes). This 2×2 design dictated that each patient would have three total brain lesions, each of a unique diameter, arranged at either 3 cm or 6 cm equidistance apart, and either all in the same or in distinctive axial planes. The simulated patient with three lesions, 6 cm apart, and all in different axial planes had a cerebellar tumor, in addition to two cerebral tumors; all other tumors were cerebral. All phantom metastases were contoured $\geq$1 cm from the brainstem, optic nerves, and optic chiasm.

VMAT treatment planning

For each patient scenario, VMAT plans were generated using a preclinical research version of the Varian Eclipse treatment planning system. At a treatment planning level, RapidArc consists of optimizing a dose distribution from the dose–volume objectives. To achieve the desired level of modulation required, the optimizer is enabled to continuously vary the instantaneous dose rate, MLC leaf positions, and gantry rotational speed (from a maximum of ~5.5°/s). The details of the planning algorithm have been previously reported (1). The preclinical version of the software allowed optimization of multiple arcs, with the limitation that the sum of the arc spans be <1,000°. The plans were created for delivery using the 6-MV SRS photon beam, with a maximal dose rate of 1,000 MU/min, on a Varian linear accelerator equipped with the Varian High Definition 120 MLC. The Varian High Definition 120 has 60 leaf pairs with a total field length of 22 cm; the leaf widths are 2.5 mm in the central 8 cm and 5 mm in the outer portion of the field. The leaf transmission of this MLC is 1% for 6 MV.

All simulated patient plans, regardless of the isocenter or number of arcs, were planned with optimization objectives stipulating a minimal dose of 20 Gy to 100% of the gross tumor volume (GTV) (the GTV was equal to the planning target volume) and a maximal dose of 10 Gy to 1% of the normal brain (normal brain was equal to the brain minus the GTVs). The dose-limiting optimization to the normal brain produced plans that minimized the volume of low-dose isodose regions but had similar conformity to plans lacking a dose-limiting stipulation for normal brain tissue. All patient plans were normalized to deliver $\geq$100% of the prescription dose (20 Gy) to all lesions. Stated differently, the isodose line that gave 100% GTV coverage was normalized to 100% (20 Gy).

Three unique treatment plans were formulated for each three-metastasis patient scenario: single-arc/single-isocenter (SASI), triple-arc/single-isocenter (TASI), and triple-arc/triple-isocenter (TATI).

Single-arc/single-isocenter. The SASI plans consisted of a standard 0° couch angle paired with a gantry rotation from a starting angle of 179°, rotating counter-clockwise through 358° to stop at a gantry angle of 181°. Throughout this study, all coordinates and scales have been used as defined by the International Electrotechnical Commission report IEC 61217. The Eclipse automated isocenter tool was used to place the isocenter.

Triple-arc/single-isocenter. The couch rotations for the TASI plans were set at 0°, 30°, and 330° for each respective arc to produce three noncoplanar arcs. This couch rotation set up stipulated that the TASI arrangements consisted of arcs of 358°, 171° (179°–350°), and 171°(181°–10°) because of the gantry rotation limitations from couch interference. The Eclipse automated isocenter tool was used to place the isocenter.

Triple-arc/triple-isocenter. The couch position for all TATI plans was set at 0° for all arcs to achieve maximal arc rotation for each arc. Because of software limitations on the sum total degrees of arc rotation (<1,000°), the TATI plans consisted of arc rotations