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**CLINICAL INVESTIGATION** **Central Nervous System**

# INITIAL EXPERIENCE WITH VOLUMETRIC IMRT (RAPIDARC) FOR INTRACRANIAL STEREOTACTIC RADIOSURGERY

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**Purpose: Initial experience with delivering frameless stereotactic radiotherapy (SRT) using volumetric intensity-modulated radiation therapy (IMRT) delivered with RapidArc is presented.**
**Methods and Materials: Treatment details for 12 patients (14 targets) with a mean clinical target volume (CTV) of 12.8 ± 4.0 $cm^3$ were examined. Dosimetric indices for conformality, homogeneity, and dose gradient were calculated and compared with published results for other frameless, intracranial SRT techniques, including CyberKnife, TomoTherapy, and static-beam IMRT. Statistics on setup and treatment times and per patient dose validations were examined.**
**Results: Dose indices compared favorably with other techniques. Mean conformality, gradient, and homogeneity index values were 1.10 ± 0.11, 64.9 ± 14.1, 1.083 ± 0.026, respectively. Median treatment times were 4.8 ± 1.7 min.**
**Conclusion: SRT using volumetric IMRT is a viable alternative to other techniques and enables short treatment times. This is anticipated to have a positive impact on radiobiological effect and for facilitating wider use of SRT.** © 2010 Elsevier Inc.

**RapidArc, Radiosurgery, Treatment time.**

## INTRODUCTION

Options for stereotactic radiosurgery with intracranial lesions have extended beyond frame-based with fixed multileaf collimator (MLC) or cone-based approaches on linear accelerators to included frameless image-guided approaches such as fixed-beam intensity-modulated radiation therapy (IMRT) (1, 2), TomoTherapy (3, 4), and CyberKnife (5–7). These allow for highly conformal treatment of lesions using technologies that are already used for routine treatment of nonstereotactic patients. In addition, the frameless approach facilitates the use of hypofractionated protocols.

Recently, arc-based IMRT techniques have emerged as a promising progression from fixed-field techniques (8–16). Modulation of the intensity over the course of an arc can enable reduction in overall treatment time and reduced dose to normal tissue structures compared with IMRT. The accuracy of volumetric IMRT using RapidArc (Varian Medical Systems, Palo Alto, CA) has been demonstrated by several investigators, indicating that it is a mature technology (17–22).

Addition of volumetric arc IMRT to the armament of image-guided techniques for delivering intracranial stereotactic radiosurgery is a natural extension of the technology. The combination of modulated intensities with an arc-based approach positions the technique intermediate to arc-based techniques using cones and fixed-beam techniques using MLCs. This report details our initial experience in the use of volumetric IMRT with RapidArc.

## METHODS AND MATERIALS

Twelve patients (Table 1) were treated between January 2009 and June 2009 with volumetric IMRT using RapidArc from Varian Medical Systems. Patients were immobilized in an alpha-cradle-based system for stereotactic radiosurgery (MayoMold, by CDR Systems www.cdrsys.ca, Alberta, Canada; Fig. 1) and then CT scanned in the treatment position using a helical scanner and slice spacing of 1.25 mm. Scans were fused with MRI. The MRI protocol adopted after

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Table 1. Characteristics of treated patients

| | |
|---|---|
| Gender | |
| Male | 8 |
| Female | 4 |
| Age | |
| 56 ± 11 years | Range, 49–81 years |
| Histology | |
| Primary diagnosis | |
| Metastatic lung | 7 |
| Melanoma | 1 |
| Metastatic esophagus | 1 |
| Metastatic breast | 1 |
| Metastatic colon | 1 |
| Metastatic renal cell | 1 |
| Chemotherapy | |
| None | 10 |
| Tarceva | 2 |
| Previous cranial irradiation | |
| Whole brain | 7 |
| Conformal Radiation Therapy | 1 |
| None | 4 |

March 2009 used T1-VIBE scans with a spacing of 1.25 mm. Target clinical target volumes (CTVs) were delineated on the fused scans and a planning target volume (PTV) was constructed with a 1- to 2-mm margin.

Patients were treated on a Trilogy accelerator (Varian Medical Systems www.varian.com, Palo Alto, CA) equipped with a Millennium 120 multileaf collimator (MLC). The accelerator is equipped with a stereotactic beam mode with a beam energy of 6 MV delivered at 1,000 MU/min with a maximum field size of 15 × 15 cm. Patients were positioned using kV planar and cone-beam CT images. The setup and localization uncertainty of this system is <1 mm. This is confirmed on treatment days with a phantom designed for end-to-end testing from CT through delivery. The phantom is illustrated in Fig. 3.

Treatment plans were created in the Eclipse (version 8.6, Varian Medical Systems, www.varian.com, Palo Alto, CA) treatment planning system with 2–3 arcs per isocenter. At least one of the arcs was noncoplanar. Figure 2 illustrates a typical approach of one 350° arc with no table rotation and a second vertex arc of ~180°. In optimization, the minimum dose constraint on the PTV was set to the prescribed dose.

A dose-limiting annulus (DLA) tuning structure (23) was created to facilitate creating a steep dose gradient beyond the PTV. The outer surface of the DLA was created with a 3-cm margin on the PTV; the inner surface was 1 mm from the PTV (Fig. 4a). The maximum dose constraint on the PTV was set to the prescribed dose. In addition, a normal tissue constraint was set that specified shape of the dose profile away from the PTV (Fig. 4b). Plans were normalized so that at least 96% of the PTV and 100% of the CTV would be covered by the prescribed dose.

Dose distributions were compared with other published SRS options using dose-conformity and dose-gradient indices. Correlations among the indices were examined. Because SRS with static MLCs with small leaves is a common approach, a hypothetical machine was created in Eclipse using the same beam data but with a high-definition MLC (0.25 cm over central 10 cm). Static MLC plans were created for each of the targets, and dosimetric indices were compared.

The conformity index of International Commission on Radiation Units and Measurements (ICRU) 62 is calculated as the ratio of the volume enclosed by the prescription isodose surface ($V_{Rx}$) to the volume of the PTV ($V_{PTV}$):

$$CI_{ICRU} = \frac{V_{Rx}}{V_{PTV}}. \quad (1)$$

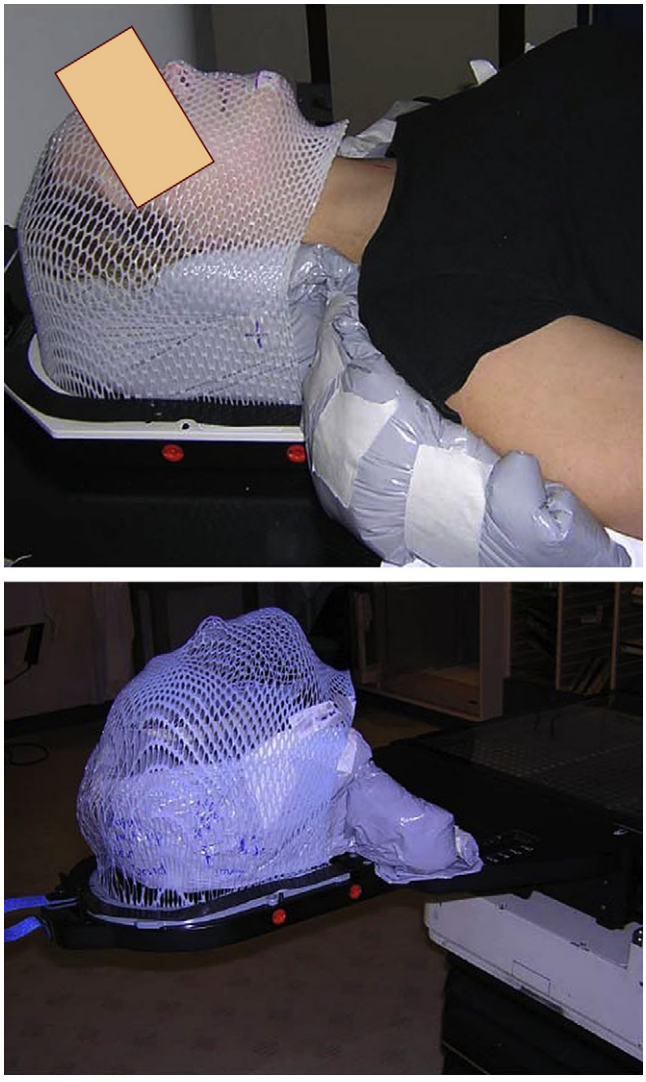

Fig. 1. (a) Patients are positioned in an alpha-cradle-based system that conforms to the posterior half of the patient from the crown of the head through the shoulders. An aquaplast mask indexes to both the cradle and the patient features when the patient is in the correct position. (b) The alpha cradle is indexed to a graphite board that cantilevers over the end of the treatment couch to facilitate used of posterior oblique angles.

Other authors have calculated the conformity index as the ratio of the volume encompassed by 95% of the prescription isodose surface ($V_{95\%Rx}$) (24).

$$CI_{95\%Rx} = \frac{V_{95\%Rx}}{V_{PTV}} \quad (2)$$

Paddick (25) noted that because the ICRU definition assumes but does not check for overlap of $V_{Rx}$ and $V_{PTV}$, false values of 1 were possible. The inverse of Paddick's formulation is used by other authors.

$$CI_{Inv-Paddick} = \frac{V_{Rx} \times V_{PTV}}{V^2_{Rx \cap PTV}}, \quad (3)$$

where $V_{Rx \cap PTV}$ is the volume of the intersection of the PTV and the prescription isodose surface.