Int. J. Radiation Oncology Biol. Phys., Vol. 77, No. 2, pp. 608–616, 2010

0360-3016/$–see front matter

ELSEVIER

doi:10.1016/j.ijrobp.2009.08.032

PHYSICS CONTRIBUTION

CLINICAL APPLICATIONS OF VOLUMETRIC MODULATED ARC THERAPY

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Purpose: To present treatment planning case studies for several treatment sites for which volumetric modulated arc therapy (VMAT) could have a positive impact; and to share an initial clinical experience with VMAT for stereotactic body radiotherapy (SBRT).
Methods and Materials: Four case studies are presented to show the potential benefit of VMAT compared with conformal and intensity-modulated radiotherapy (IMRT) techniques in pediatric cancer, bone marrow–sparing whole-abdominopelvic irradiation (WAPI), and SBRT of the lung and spine. Details of clinical implementation of VMAT for SBRT are presented. The VMAT plans are compared with conventional techniques in terms of dosimetric quality and delivery efficiency.
Results: Volumetric modulated arc therapy reduced the treatment time of spine SBRT by 37% and improved isodose conformality. Conformal and VMAT techniques for lung SBRT had similar dosimetric quality, but VMAT had improved target coverage and took 59% less time to deliver, although monitor units were increased by 5%. In a complex pediatric pelvic example, VMAT reduced treatment time by 78% and monitor units by 25% compared with IMRT. A double-isocenter VMAT technique for WAPI can spare bone marrow while maintaining good delivery efficiency.
Conclusions: Volumetric modulated arc therapy is a new technology that may benefit different patient populations, including pediatric cancer patients and those undergoing concurrent chemotherapy and WAPI. Volumetric modulated arc therapy has been used and shown to be beneficial for significantly improving delivery efficiency of lung and spine SBRT. © 2010 Elsevier Inc.

Volumetric modulated arc therapy, VMAT, IMAT.

INTRODUCTION

Intensity-modulated arc therapy (IMAT) was introduced by Yu in 1995 as a competing radiation therapy delivery modality to intensity-modulated radiotherapy (IMRT) and tomographic delivery techniques (1). Until recently, the major drawback to IMAT delivery was that modern linear accelerators could not deliver plans at varying angular dose rates (monitor units [MU]/°), and therefore multiple arc plans were necessary to achieve the IMAT dose distributions. Planning exercises have suggested that varying angular dose rates could lead to efficient delivery of IMAT plans, by allowing a reduction in the number of arcs and treatment time required (2–5). Linear accelerator vendors have now released the capability to vary the angular dose rate by dynamically changing dose rate and/or gantry speed during an arc delivery. This new capability, referred to as volumetric modulated arc therapy or VMAT, has likely spurred a re-emergence of clinical interest in the use of arc therapy. Studies have suggested that VMAT may be useful in a variety of treatment sites (4, 6–11).

An advantage of VMAT is the potential reduction in delivery time compared with IMRT. Otto (6) has suggested that a 200-cGy fraction can be delivered in 1.5–3 min with VMAT, and Verbakel *et al.* and Clivio *et al.* have demonstrated 75–80% time reductions in head-and-neck and anal cancer VMAT plans, respectively, vs. IMRT (7, 8). Treatment time reductions may play a role in reducing both patient discomfort and the potential for intrafraction motion. Stereotactic body radiotherapy (SBRT), for instance, is a modality in which treatment times (excluding patient setup) exceed 20 min. Because a large number of beams with close gantry spacing is already used for SBRT, the extension to VMAT is natural and could significantly benefit the patient.

A reduction in monitor units (MU) is also a perceived benefit with a VMAT technique compared with IMRT. This feature would benefit all patient populations by improving delivery efficiency and could have an even greater impact on patients for whom the induction of secondary malignancies may be a factor because of life expectancy. For example,

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Conflict of interest: This work was partially supported by Elekta. M.M.M. has received honoraria from Elekta in the past for invited presentations.

Received April 6, 2009, and in revised form Aug 4, 2009. Accepted for publication Aug 17, 2009.

concerns over high MU and overall dose in pediatric cases suggest that VMAT may be an excellent alternative to IMRT in complicated cases in which proton therapy is not an available or cost-effective option.

Volumetric modulated arc therapy could make it possible to treat complicated sites in which IMRT plans are not practical owing to poor delivery efficiency. In head-and-neck cancer it may be more feasible to limit dysphagia using a VMAT technique (12), and the use of IMAT in the treatment of endometrial malignancies to improve dose homogeneity and facilitate bone marrow sparing has also been suggested (2, 5). With dose rate and gantry speed modulation, fast delivery of marrow-sparing whole-abdominopelvic irradiation (WAPI) using VMAT may be possible.

As with any new treatment delivery technique, it is important to consider which patient population may benefit the most from the new technology and attempt to focus clinical interest and research into developing techniques. The purpose of this work is to introduce and present treatment planning case studies for several clinical applications in which VMAT may have a substantial benefit, including radiosurgery of the lung and spine, treatment of pediatric cancers, and WAPI. We will also present our initial clinical experience with VMAT—as derived from the SBRT case studies in the spine and lung, which were treated using VMAT—including practical issues, such as treatment planning, quality assurance (QA), and current limitations.

METHODS AND MATERIALS

Four patient case studies will be presented to demonstrate the benefit of VMAT compared with the current clinical practice at our institution. We will present our clinical experience with stereotactic radiosurgery to the lung and spine using VMAT, as well as a retrospective planning and treatment simulation study showing the potential benefit of VMAT for a pediatric cancer case and in WAPI. Dose distributions and metrics, dose–volume histograms (DVHs), MU, and delivery time will be compared for VMAT techniques vs. conventional or IMRT treatments.

Patients at our institution can be treated with VMAT under a human investigational committee (HIC)-approved study. In addition, existing HIC-approved protocols for lung and spine SBRT have been amended to include VMAT as a treatment modality option. Retrospective patients can be evaluated for VMAT treatment under an approved treatment planning study.

Stereotactic radiosurgery of the lung

A patient with Stage T1N0M0 non–small-cell lung cancer was enrolled in our lung SBRT protocol and underwent four-dimensional CT simulation and contour generation as described previously (13). The protocol is a single-institution, nonrandomized, prospective Phase II study of hypofractionated stereotactic radiotherapy to evaluate the impact of the technique on local control rates of non–small-cell lung cancers and metastatic lung tumors. Radiotherapy is delivered over 8–14 days in 4 to 5 fractions, depending on tumor size and histology. The present patient was prescribed 48 Gy in 12-Gy fractions to the planning target volume (PTV). Conventionally, patients receive an optimized aperture plan consisting of seven to nine beams. A similar plan was completed for this patient to use as a comparison and alternate plan if the VMAT plan was not used. A partial VMAT arc (31°–219°) was planned to limit contralateral lung dose.

Table 1. Planning goals and results for the spine radiosurgery case

Structure	Metric*	Goal (Gy)	IMRT plan (Gy)	VMAT plan (Gy)
PTV	D90	—	16.8	17.1
	D80	18	18.3	18.3
GTV	D90	—	17.2	18.0
Cord†	Max	8	4.1	3.9
Cord + 3 mm	Max	10	8.1	8.0
Esophagus	Max	10	7.1	7.7

Abbreviations: IMRT=intensity-modulated radiotherapy; VMAT= volumetric modulated arc therapy; PTV = planning target volume; GTV = gross tumor volume.

* Max defined as maximum dose to 0.1 cm^3 of the structure volume.

† Spinal cord defined on magnetic resonance imaging.

Stereotactic radiosurgery of the spine

A patient prescribed to receive palliative treatment for a metastasis in the T10 vertebral body was selected for VMAT treatment. The patient was treated according to our spine radiosurgery protocol that uses the dosimetric guidelines in Table 1. This protocol is a single-institution, prospective, nonrandomized Phase II study of image-guided stereotactic radiosurgery for limited spinal metastases with a purpose of evaluating the impact of stereotactic radiosurgery on the symptomatic palliation of pain and prevention and/or relief of neurologic symptoms. Patients receive 16–18 Gy to the PTV in 1 fraction, limited by the normal tissue dose constraints. Before VMAT planning for the present patient, an IMRT plan was generated. Beams covered from 90° to 270°. A partial-arc VMAT treatment covering the same beam angles was created and optimized. It is our clinical procedure to keep MU as low as possible in spine SBRT IMRT plans by allowing only one to two segments per beam. This also reduces treatment time and ensures that larger segments are used.

Pediatric cancer

A 3-year-old patient who had undergone a cystoprostatectomy for a recurrent rhabdomyosarcoma outside of a previously treated high-dose-rate brachytherapy volume was prescribed IMRT to the pelvic nodal regions. Intensity-modulated radiotherapy was deemed necessary to facilitate sparing of normal tissues owing to the patient's age and previous treatment status. A retrospective VMAT plan was created and compared with the treated eight-field IMRT plan. The pelvic region was prescribed 50.4 Gy with the exception of the PTV–bowel overlap, which was relaxed to prevent any hotspots in the bowel. Dose to the rectum, bone marrow, femoral heads, and remaining normal tissues was reduced as much as possible. Effort was also made to use the lowest number of segments and MU necessary to reduce overall dose to the patient and reduce treatment time, because the patient was treated under anesthesia.

Whole-abdominopelvic irradiation

A patient treated with conventional WAPI was retrospectively planned for WAPI-VMAT. Our conventional technique is an antero-posterior/posteroanterior beam arrangement with blocks for the liver and kidneys (14, 15). With this technique, a large amount of bone marrow receives the full dose. It has been reported that 15–20% of