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VMAT *VS.* 7-FIELD-IMRT: ASSESSING THE DOSIMETRIC PARAMETERS OF PROSTATE CANCER TREATMENT WITH A 292-PATIENT SAMPLE

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Abstract—We compared normal tissue radiation dose for the treatment of prostate cancer using 2 different radiation therapy delivery methods: volumetric modulated arc therapy (VMAT) *vs.* fixed-field intensity-modulated radiation therapy (IMRT). Radiotherapy plans for 292 prostate cancer patients treated with VMAT to a total dose of 7740 cGy were analyzed retrospectively. Fixed-angle, 7-field IMRT plans were created using the same computed tomography datasets and contours. Radiation doses to the planning target volume (PTV) and organs at risk (bladder, rectum, penile bulb, and femoral heads) were measured, means were calculated for both treatment methods, and dose-volume comparisons were made with 2-tailed, paired *t*-tests. The mean dose to the bladder was lower with VMAT at all measured volumes: 5, 10, 15, 25, 35, and 50% ($p < 0.05$). The mean doses to 5 and 10% of the rectum, the high-dose regions, were lower with VMAT ($p < 0.05$). The mean dose to 15% of the rectal volume was not significantly different ($p = 0.95$). VMAT exposed larger rectal volumes (25, 35, and 50%) to more radiation than fixed-field IMRT ($p < 0.05$). Average mean dose to the penile bulb ($p < 0.05$) and mean dose to 10% of the femoral heads ($p < 0.05$) were lower with VMAT. VMAT therapy for prostate cancer has dosimetric advantages for critical structures, notably for high-dose regions compared with fixed-field IMRT, without compromising PTV coverage. This may translate into reduced acute and chronic toxicity. © 2011 American Association of Medical Dosimetrists.

Key Words: **VMAT, IMRT, Prostate cancer, RapidArc.**

INTRODUCTION

It is well documented that high-dose external beam radiation therapy for prostate cancer carries clinical and biochemical benefits.[1–4] The emergence of 3-D conformal radiotherapy (3-D CRT) provided a modality for dose escalation with acceptable radiation dose to healthy tissue.[5] Intensity-modulated radiation therapy (IMRT) further empowers radiation oncologists with the ability to deliver a more conformal, higher-dose treatment to the planning target volume (PTV) while decreasing dose to critical organs and other healthy tissue.[6–8] Fixed-field IMRT, as it applies in this case, administers radiation from a predetermined number of fixed beam angles using inverse planning algorithms and a dynamic multileaf collimator (DMLC) delivery technique known as *sliding window*. Zelefsky *et al.* showed that compared with 3D-CRT, IMRT treatment at 81 Gy resulted in less rectal toxicity manifested as a decreased incidence of grade 2 or higher GI toxicity.[9] Bladder toxicity was also more favorable.[9] Therefore, IMRT is considered the standard of care for patients undergoing external beam radiation therapy for prostate cancer.

Multiple studies address the relationship between specific dose-volume constraints and organ toxicity. Pollack *et al.* and Huang *et al.* suggest that when >25% of the rectum is irradiated to ≥70 Gy, patients have a higher probability of developing grade 2 or higher rectal toxicity.[4,10] Moreover, according to Kupelian *et al.*, rectal bleeding correlates with an absolute rectal volume of 15 cm^3 irradiated to more than 78 Gy.[11] Genitourinary toxicity is related to the treatment of the prostate gland and exposure to the bladder. IMRT techniques are used to minimize the radiation dose to the bladder.[12,13] Consequently, dose escalation to improve tumor control and clinical outcomes is impeded by the necessity to limit exposure to these organs at risk (OARs).

A novel form of IMRT delivery known as *volumetric modulated arc therapy* (VMAT) is capable of delivering dose to the PTV in a single gantry revolution. VMAT integrates DMLC with dose-rate and gantry-speed modulation to deliver the treatment. Unlike fixed-field IMRT, where a limited number of fixed angles are optimized to meet planning constraints, VMAT optimization algorithms incorporate a full rotational range of beam angles to meet the same constraints. This freedom of beam geometry coupled with dose-rate and gantry-speed modulation provides the potential for achieving higher dose conformity to the PTV and tighter constraints on OAR limits.

Several studies suggest an enhanced treatment efficacy with VMAT radiotherapy compared with fixed-field

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IMRT.[14–19] Palma *et al.* demonstrated a more favorable dose distribution to the prostate and OARs, with reduced monitor units using VMAT compared with conventional IMRT.[20] Furthermore, treatment beam-on time is reduced by 55% in prostate cases,[21,22] thereby possessing the potential to decrease error from intrafraction organ motion. VMAT provides radiation oncologists an additional tool to manipulate dose-volume constraints and minimize toxicity to OARs. This paper compares VMAT treatment plans with fixed-field IMRT plans created for the same prostate cancer patients.

METHODS AND MATERIALS

Institutional review board ethics approval was granted for this study. Patients with prostate cancer treated at 2 different radiation centers were reviewed retrospectively. We identified patients treated to a total dose of 7740 cGy delivered in 43 fractions with VMAT *via* RapidArc (Varian Medical Systems, Palo Alto, CA). Fixed-angle 7-field IMRT plans were created for comparison using the same computed tomography (CT) datasets and contoured structures. No specific patient identifiers were used.

Three gold seed fiducial markers were implanted in the prostate, which were used for daily image-guided radiation therapy using orthogonal kV imaging or cone-beam CT. Approximately one week later, patients underwent CT simulation in the supine position with their legs immobilized using a vac-lok. A previous bowel prep ensured an evacuated rectum and patients were scanned with the sensation of a comfortably full bladder. Most patients underwent a T2-weighted magnetic resonance imaging (MRI) scan as part of the planning process. The CT and MRI images were then registered with one another within the Eclipse treatment planning system (TPS). CT and MRI image fusion was used to better delineate the prostate, especially near its apex and to better visualize the presence of any intravesical component.

Contouring of structures was standardized based on guidelines set forth by RTOG protocol 0126. The gross tumor volume was contoured to encompass the prostate. Margins were applied 5 mm posteriorly and 7 mm radially in other dimensions to create the PTV. Seminal vesicles and lymph nodes were not included in the treatment volume; however, portions of the seminal vesicles were automatically encompassed within the PTV. OARs were contoured, including the bladder from dome to base, rectum from the anus for a length of 15 cm or to the rectosigmoid flexure, femoral heads to the level of the ischial tuberosities, and penile bulb. RTOG guidelines for conformality and homogeneity of dose within the PTV were adopted as treatment planning goals. The prescribed dose was 7740 cGy delivered in 180 cGy daily fractions with a goal of at least 98% of the PTV to receive the prescribed dose and no more than 2% of its volume to receive a maximum of 107% of the prescribed dose.

Both fixed-field IMRT and VMAT plans were generated using the Eclipse external beam TPS, version 8.5. Fixed-field IMRT plans used 7-beam angles: 0°, 53°, 104°, 154°, 206°, 256°, and 307°. To meet plan objectives, optimization of dose was carried out by the dose-volume optimizer (DVO) of the TPS. Dose calculations were performed using the anisotropic analytical algorithm (AAA).[23] In contrast, beam geometry for the VMAT plans spanned 358°, rotating from a gantry angle of 179–181°. Collimator angles were automatically optimized for each plan and typically resulted in a collimator angle of 45°. For the Eclipse TPS, optimization of dose according to plan objectives is fundamentally different for VMAT than for fixed-field IMRT. For VMAT, optimization is carried out by the progressive resolution optimizer (PRO), which considers the plan objectives for an increasing number of beam angles commensurate with the optimizer's 5 resolution levels. Dose calculations were performed using the same AAA algorithm as in fixed field plans.

Plan optimization objectives, including the normal tissue objective, were consistent for both treatment planning techniques. Optimization objectives were set to parallel acceptable PTV coverage and OAR dose-volume constraints according to RTOG protocol, as summarized in Table 1. All plans used 6-MV photons and a dose calculation grid size of 2.5 mm, which incorporated heterogeneity corrections. Treatment delivery used the Varian Clinac 2100iX linac with 120-leaf multileaf collimator (MLC) or the Varian Trilogy linac with 120-leaf MLC.

The radiation oncologists and planners involved used a standardized set of contouring guidelines and optimization objectives. This resulted in consistent planning results that met the standard of care at our institution for both techniques. In fact, plans almost unanimously exceeded the objectives in Table 1. Fixed-field IMRT and VMAT plans used identical CT datasets and the exact same contours. The time to

Table 1. Plan objective criteria: Optimization objectives were set to parallel acceptable PTV coverage and OAR dose-volume constraints according to RTOG protocol[25]

PTV/CTV Criteria (RTOG0126)	
Percentage of PTV receiving less than IMRT dose	≤2%
Percentage of CTV receiving less than IMRT dose	0%
% Maximum dose (hot spot) to 2% of PTV	≤7%

Organs At Risk Criteria (RTOG0126)		
	Bladder	Rectum
%Volume	Target (Gy)	Target (Gy)
15%	≤80	≤75
25%	≤75	≤70
35%	≤70	≤65
50%	≤65	≤60

Femoral head: No more than 10% volume receives dose that exceeds 50 Gy.
Penile bulb: Mean dose less than or equal to 52.5 Gy.