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PHYSICS CONTRIBUTION

ASSESSING THE ROLE OF VOLUMETRIC MODULATED ARC THERAPY (VMAT) RELATIVE TO IMRT AND HELICAL TOMOTHERAPY IN THE MANAGEMENT OF LOCALIZED, LOCALLY ADVANCED, AND POST-OPERATIVE PROSTATE CANCER

Melanie T. M. Davidson, Ph.D.,* Samuel J. Blake, B.Sc.,* Deidre L. Batchelar, Ph.D.,*‡
Patrick Cheung, M.D., FRCPC.,†‡ and Katherine Mah, M.Sc.*‡

From the Departments of *Medical Physics and †Radiation Oncology, Odette Cancer Centre, Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada; ‡Department of Radiation Oncology, University of Toronto, Toronto, Ontario, Canada

Purpose: **To quantify differences in treatment delivery efficiency and dosimetry between step-and-shoot intensity-modulated radiotherapy (IMRT), volumetric modulated arc therapy (VMAT), and helical tomotherapy (HT) for prostate treatment.**
Methods and Materials: **Twenty-five prostate cancer patients were selected retrospectively for this planning study. Treatment plans were generated for: prostate alone (n = 5), prostate + seminal vesicles (n = 5), prostate + seminal vesicles + pelvic lymph nodes (n = 5), prostate bed (n = 5), and prostate bed + pelvic lymph nodes (n = 5). Target coverage, dose homogeneity, integral dose, monitor units (MU), and sparing of organs at risk (OAR) were compared across techniques. Time required to deliver each plan was measured.**
Results: **The dosimetric quality of IMRT, VMAT, and HT plans were comparable for target coverage (planning target volume V95%, clinical target volume V100% all >98.7%) and sparing of organs at risk (OAR) for all treatment groups. Although HT resulted in a slightly higher integral dose and mean doses to the OAR, it yielded a lower maximum dose to all OAR examined. VMAT resulted in reductions in treatment times over IMRT (mean = 75%) and HT (mean = 70%). VMAT required 15–38% fewer monitor units than IMRT over all treatment volumes, with the reduction per fraction ranging from 100–423 MU from the smallest to largest volumes.**
Conclusions: **VMAT improves efficiency of delivery for equivalent dosimetric quality as IMRT and HT across various prostate cancer treatment volumes in the intact and postoperative settings.** **© 2011 Elsevier Inc.**

intensity-modulated radiotherapy, Volumetric modulated arc therapy, Helical tomotherapy, Prostate cancer, Efficiency.

INTRODUCTION

Advanced forms of external beam radiotherapy, characterized by the use of intensity-modulated radiation beams to create more conformal dose distributions, are emerging as a standard of care for prostate cancer. These distributions can be created via multiple static portals (step-and-shoot intensity-modulated radiotherapy [IMRT]) or dynamic fields in the form of sliding-window IMRT, volumetric modulated arc therapy (VMAT), and helical tomotherapy (HT). Although different methods of delivering IMRT are possible, there is no consensus regarding the superiority of any one technique because systematic comparisons of clinical treatment plans from multiple IMRT approaches are not readily available.

Planning studies comparing advanced techniques for low- and intermediate-risk prostate cancers have been emerging, including comparisons of IMRT to VMAT (1–3), HT to intensity-modulated arc therapy (IMAT) (4), and VMAT to IMRT and serial tomotherapy (MIMiC) (5) or HT (6). The target volume for low-risk patients is confined to the prostate, and may extend to include portions of the seminal vesicles for intermediate-risk patients. Plans for these relatively small and regularly shaped targets can usually be designed to deliver a therapeutic dose to the target while respecting dose constraints to normal structures, including bladder and rectum. Studies looking at low-risk prostate cases found that VMAT provides improved target coverage and organ at risk (OAR) sparing compared with a five-field IMRT (1) and produces comparable dose–volume histogram (DVH) indices to HT (4). For intermediate-risk cases, VMAT offers some improvements in plan quality (2, 3) over IMRT and treatment efficiency (2, 5, 6) over IMRT, MIMiC, and HT.

Reprint requests to: Melanie T. M. Davidson, Ph.D., Department of Medical Physics, Odette Cancer Centre, Sunnybrook Health Sciences Centre, 2075 Bayview Avenue, TG-217c, Toronto, Ontario, Canada M4N 3M5. Tel: (416) 480-6100 ext. 1089; Fax: (416) 480-6801; E-mail: melanie.davidson@sunnybrook.ca

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Few studies have evaluated advanced radiotherapy techniques in high-risk groups. These cases present a more challenging planning task because of both the larger target volumes required and the separate dose targets. Target volumes for higher risk cases can include the prostate, seminal vesicles, and pelvic lymph nodes (LN), resulting in targets that are large, irregularly shaped, and surrounded to a significant extent by normal tissues. Thus, it is more difficult to achieve adequate dose coverage while maintaining acceptable OAR dose levels.

Some investigators have explored delivering IMRT or HT using a simultaneous integrated boost (SIB) strategy in the high-risk prostate setting. Li *et al.* (7) explored the feasibility of the SIB approach using IMRT and have shown that this results in better sparing of OAR and more efficient delivery than conventional two-phase treatment schemes for these patients. Yuen *et al.* (8) evaluated HT for the treatment of this population using the SIB technique and found SIB-HT to have similar dosimetric advantages as IMRT when compared with three-dimensional conformal radiation therapy (3D-CRT). There are no published studies comparing VMAT with IMRT or HT for treatment of high-risk prostate cancer.

For postprostatectomy patients in whom radiotherapy is used in the adjuvant or salvage setting, applying IMRT techniques to treat the prostate fossa may improve the therapeutic ratio (9). The postsurgical clinical target volume (CTV) boundaries defined in a recent Radiation Therapy Oncology Group (RTOG) consensus (10) give rise to a complex CTV geometry, making these cases more complicated to plan for radiotherapy than intact prostate cases. The CTV's irregular shape, along with the proximity of the posterior border to the anterior rectal wall (inferiorly) and anterior extension into the bladder wall (superiorly), make it particularly difficult to sculpt dose away from the bladder and rectum. Koontz *et al.* (11) demonstrated that IMRT provides better high dose sparing of the normal critical structures than 3D-CRT. Similarly, Cozzarini *et al.* demonstrated a benefit for HT compared with 3D-CRT with regards to rectal sparing (9). To the best of our knowledge, a comparison of VMAT, IMRT, and HT for postprostatectomy irradiation has not been reported.

For postprostatectomy patients at higher risk of nodal involvement, the irradiation of pelvic LN may improve outcomes by potentially eradicating nodal micrometastases (12). However, although there may be benefits with regards to disease control, the larger volumes irradiated for these patients may result in increased doses to surrounding OAR, including rectum, bladder, and small bowel. A study by Alongi *et al.* (13) demonstrated that IMRT and HT offered significant advantages over 3D-CRT with regards to genitourinary and gastrointestinal toxicities. Further, they demonstrated that HT offered superior sparing of the rectum and bowel compared with IMRT. The role of VMAT has not been evaluated for this cohort.

Despite all these reports, no study has simultaneously evaluated plans from multiple advanced treatment approaches across all of the possible prostate treatment volumes described previously. In this planning study, we quantitatively compare treatment plans for IMRT, VMAT, and HT, developed for treatment volumes associated with different prostate cancer risk groups both in the intact prostate and postoperative settings. Plan quality, based on dosimetric parameters, will be compared for all three techniques.

The highly conformal doses attained with complex radiotherapy techniques generally come at the cost of prolonged delivery time and increased patients exposure to leakage because of increases in monitor units (MU). Thus, one important comparator amongst the techniques examined was treatment delivery efficiency (delivery time and MU).

Based on these data, we assess the role of IMRT, VMAT, and HT in radiotherapy for prostate cancer, according to the volume requiring treatment.

METHODS AND MATERIALS

Patient selection

This study was approved by the Sunnybrook Health Sciences Centre Research Ethics Board. Eligible patients for this comparative planning study included patients previously treated at our center for prostate cancer with either IMRT or HT. Five patients in each of the following target categories were randomly selected:

a) prostate
b) prostate + seminal vesicles
c) prostate + seminal vesicles + pelvic LN (obturator, iliac, and presacral LN as per RTOG consensus) (14)
d) prostate bed (postprostatectomy as per RTOG consensus) (10)
e) prostate bed + pelvic LN (obturator, iliac, and presacral LN) (14)

In this study, patients were scanned in a vacuum-lock device using a non-contrast computed tomography (1.5 mm slice thickness) with a full bladder and empty rectum. The following structures were contoured: prostate (or prostate bed), entire bladder, rectum (from ischium to sigmoid flexure ~11–13 cm), and femoral heads. For groups a, b, and d, the CTV consisted of the structures defined by the category, whereas the planning target volume (PTV) was the CTV plus 1cm in the lateral, anterior and craniocaudal directions. Although clinically the PTV margin is often reduced posteriorly to achieve better rectal sparing, the 1-cm margin was maintained for this study to increase the planning task challenge across techniques. The higher risk groups (c and e) have both a nodal PTV, comprising the pelvic LN plus a 6-mm nodal PTV margin, and a non-nodal PTV, consisting of prostate+seminal vesicles or prostate bed plus a 1-cm margin. All contours were reviewed by one radiation oncologist (P.C.).

Intact prostate cases: planning objectives

Planning objectives for the PTVs and OARs are listed in Table 1a, for the lower risk prostate cases (categories a, b), and Table 1b, for the higher risk cases (category c). Lower risk prostate patients were prescribed a dose of 78 Gy in 39 fractions. Higher risk prostate cases were planned using a hypofractionation scheme derived from the literature, calculated based on the biologically equivalent dose (BED) for acute toxicity and tumor response (15–17). This regimen consisted of 68 Gy delivered to the prostate+seminal vesicles, with 45 Gy simultaneously delivered to the nodal volumes, in 25 fractions. This fractionation is