

Original Article

Feasibility of the partial-single arc technique in RapidArc planning for prostate cancer treatment

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Abstract

The volumetric modulated arc therapy (VMAT) technique, in the form of RapidArc, is widely used to treat prostate cancer. The full-single arc (f-SA) technique in RapidArc planning for prostate cancer treatment provides efficient treatment, but it also delivers a higher radiation dose to the rectum. This study aimed to compare the dosimetric results from the new partial-single arc (p-SA) technique with those from the f-SA technique in RapidArc planning for prostate cancer treatment. In this study, 10 patients with low-risk prostate cancer were selected. For each patient, two sets of RapidArc plans (f-SA and p-SA) were created in the Eclipse treatment planning system. The f-SA plan was created using one full arc, and the p-SA plan was created using planning parameters identical to those of the f-SA plan but with anterior and posterior avoidance sectors. Various dosimetric parameters of the f-SA and p-SA plans were evaluated and compared for the same target coverage and identical plan optimization parameters. The f-SA and p-SA plans showed an average difference of $\pm 1\%$ for the doses to the planning target volume (PTV), and there were no clear differences in dose homogeneity or plan conformity. In comparison to the f-SA technique, the p-SA technique reduced the doses to the rectum by approximately 6.1% to 21.2%, to the bladder by approximately 10.3% to 29.5%, and to the penile bulb by approximately 2.2%. In contrast, the dose to the femoral heads, the integral dose, and the number of monitor units were higher in the p-SA plans by approximately 34.4%, 7.7%, and 9.2%, respectively. In conclusion, it is feasible to use the p-SA technique for RapidArc planning for prostate cancer treatment. For the same PTV coverage and identical plan optimization parameters, the p-SA technique is better in sparing the rectum and bladder without compromising plan conformity or target homogeneity when compared to the f-SA technique.

Key words Prostate cancer, RapidArc, partial arc, volumetric modulated arc therapy (VMAT), planning technique

Prostate cancer is the second most commonly diagnosed cancer among men in the United States after skin cancer^[1]. Radiotherapy is one option for the management of prostate cancer. In recent years, the volumetric modulated arc therapy (VMAT) technique has been widely used to treat prostate cancer because VMAT allows the delivery of a conformal dose distribution to the PTV while minimizing the doses to nearby critical structures^[2]. Furthermore, VMAT requires

a smaller number of monitor units (MUs) to deliver a given fraction size, and treatment can be completed in a shorter treatment time than that required for intensity-modulated radiation therapy (IMRT)^[2-4]. RapidArc (Varian Medical Systems, Palo Alto, CA) is one such VMAT technique that can deliver treatments over one or several continuous arcs with the simultaneous adjustment of dose rate, gantry rotation speed, and multi-leaf collimator (MLC) field aperture^[2,3]. Previous studies on RapidArc planning for prostate cancer treatment have mostly focused on comparing the dosimetric quality of treatment techniques, such as IMRT vs. RapidArc^[5-11] and single arc (SA) vs. double arc (DA)^[8-11] in RapidArc planning.

The RapidArc treatment planning requires a trade-off between target coverage and the sparing of critical structures. Treatment planners can modify the plans by varying the weight factor for each target or critical structure during the optimization process. Additionally, dose-volume parameters can also be varied to meet the acceptable

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dosimetric criteria. However, plan optimization may not produce the optimal plan, and the treatment planner may need to repeat the optimization. For example, if the treatment plan requires a reduction in the dose to the rectum, the planner will need to re-optimize the plan using either different beam parameters or an increased weight factor for the rectum, which may reduce the target coverage. Thus, treatment planning can require a trial-and-error process to find an optimal plan.

Sze *et al.*^[9] reported that although the SA technique for RapidArc planning for prostate cancer treatment could provide treatment efficiency, which is important for busy clinics with high patient throughput, it also delivers a higher dose to the rectum. It is essential to find more efficient methods for RapidArc planning using the SA technique while minimizing the radiation dose to critical structures such as the rectum and bladder. In this study, we investigated the feasibility of RapidArc planning using SA with anterior and posterior avoidance sectors on prostate cancer planning. The dosimetric quality of the new partial-single arc (p-SA) technique was compared with that of the full-single arc (f-SA) technique for the same target coverage and identical plan optimization parameters.

Patients and Methods

Patient selection

We randomly selected 10 cases from the database of low-risk prostate cancer treated with external beam radiation therapy at West Hills Radiation Therapy Center, Vantage Oncology, California, USA between January 2012 and January 2013.

Computed tomography (CT) simulation

All patients underwent standard CT simulation, maintaining full bladder during the simulation process, and were immobilized in a Vac-Lok system (CIVCO Medical Solutions, Kalona, Iowa, USA). CT scans of 512×512 pixels and 0.25 cm slices were acquired using a GE LightSpeed CT Scanner (GE Healthcare, Milwaukee, WI, USA). After the CT simulation, Digital Imaging and Communications in Medicine (DICOM) CT images were transferred to the Varian Eclipse treatment planning system (TPS) for contouring and planning preparation.

Contouring

The clinical target volume (CTV) comprised of prostate and proximal seminal vesicles were contoured by a radiation oncologist on the axial CT images. The rectum, bladder, and femoral heads, defined as organs at risk (OARs), were delineated based on the axial CT images. The planning target volume (PTV) was generated from the CTV by a uniform expansion of 5 mm in all directions.

Dose prescription and planning

The total dose prescribed to the PTV was 79.2 Gy with a daily

dose of 1.8 Gy in 44 fractions. The planning parameters were set up using Varian standard scale in the Eclipse TPS (version 11.0.21) with Varian Clinac iX 6 MV X-ray beams (Varian Medical Systems, Palo Alto, CA, USA). For each patient, two sets of RapidArc plans (f-SA and p-SA) were created, and the isocenter was placed at the center of the PTV for both plans. First, the f-SA plan was created using one full arc in an anti-clockwise direction (arc angle: $1^\circ \rightarrow 359^\circ$; collimator angle: 170°) (**Figure 1A**). Then, the p-SA plan was created using parameters identical to those of the f-SA plan but with an anterior avoidance sector of 30° and a posterior avoidance sector of 60° (**Figure 1B**). Specifically, in the p-SA plan, the beam-on fraction was in the arc sections from 30° to 165° and from 195° to 330° .

Optimization

Ten sets of plans (f-SA and p-SA) were inversely optimized using the Varian Eclipse Progressive Resolution Optimizer (PRO, version 11.0.21). To make fair comparisons between the f-SA and p-SA plans, a volumetric dose optimization template (**Table 1**) was created to ensure that at least 95% of the PTV received the prescription dose in 44 fractions while keeping the dose to OARs below the planning limits. For the rectum, the percent volume receiving ≥ 60 Gy, ≥ 65 Gy, ≥ 70 Gy, and ≥ 75 Gy ($V_{60\text{Gy}}$, $V_{65\text{Gy}}$, $V_{70\text{Gy}}$, and $V_{75\text{Gy}}$, respectively) was restricted to 50%, 35%, 25%, and 15%, respectively. For the bladder, the $V_{65\text{Gy}}$, $V_{70\text{Gy}}$, $V_{75\text{Gy}}$, and $V_{80\text{Gy}}$ was restricted to 50%, 35%, 25%, and 15%, respectively. The mean dose to the femoral heads was limited to less than 30 Gy. No modifications of the dose-volume constraints or weightings were made during the optimization processes for either set of plans.

Calculation and normalization

The doses from optimized f-SA and p-SA plans were calculated with the Anisotropic Analytical Algorithm (AAA), version 11.0.21, in the Eclipse TPS, and the dose calculation grid was set to 2.5 mm for all cases. The calculated f-SA and p-SA plans were then normalized such that the prescribed dose covered at least 95% of the PTV.

Evaluation

The dose-volume histograms (DVHs) of normalized f-SA and p-SA plans were generated in the Eclipse TPS. For the PTV, the minimum dose, mean dose, maximum dose, conformity index (CI, defined in equation 1), and homogeneity index (HI, defined in equation 2) were compared.

$$CI = \frac{V_{95\%}}{V_{PTV}} \quad (1),$$

where $V_{95\%}$ is the total volume of the isodose cloud receiving 95% of the prescription dose, and V_{PTV} is the volume of the PTV.

$$HI = \frac{D_{5\%}}{D_{95\%}} \quad (2),$$

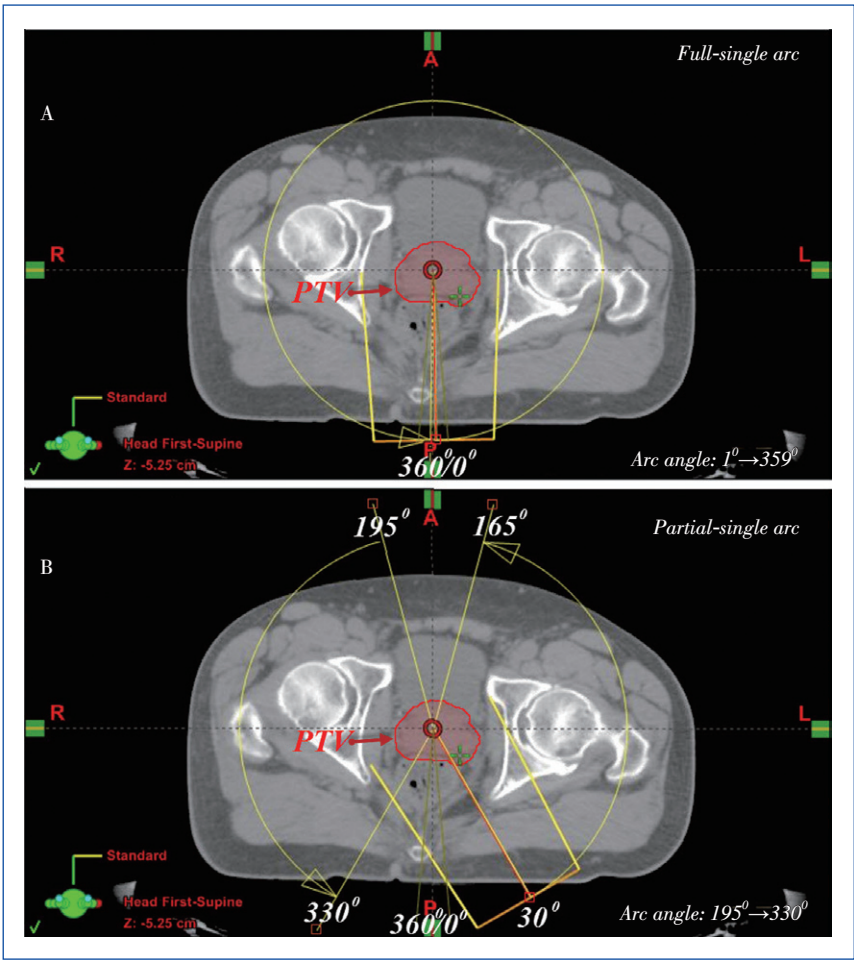


Figure 1. A transversal view of the RapidArc plan for prostate cancer using two planning techniques in the Eclipse treatment planning system (Varian Standard Scale). A, full–single arc (f-SA) with continuous beam-on time from arc angle 1° to 359°. B, partial–single arc (p-SA) with beam-on time from arc angle 30° to 165° and from arc angle 195° to 330°. The p-SA technique includes a posterior avoidance sector (60°) and an anterior avoidance sector (30°). PTV, planning target volume.

Table 1. Dose-volume constraints and weightings used for the optimization in RapidArc planning for prostate cancer treatment using the full–single arc (f-SA) and partial–single arc (p-SA) techniques

Structure	Optimization objective	Volume (%)	Dose (Gy)	Weighting
PTV	Upper	0	81.5	250
	Lower	100	80.5	250
Rectum	Upper	0	78.0	85
	Upper	15	70.0	85
	Upper	35	60.0	85
	Upper	50	50.0	85
Bladder	Upper	0	78.0	80
	Upper	15	75.0	80
	Upper	35	65.0	80
	Upper	50	60.0	80
Femoral heads	Upper	0	55.0	80
	Upper	10	50.0	80

PTV, planning target volume. Optimization objective corresponds to a point in the dose-volume data space. The upper and lower objectives represent the maximum and minimum limits, respectively, to the corresponding dose-volume histogram.

where $D_{5\%}$ and $D_{95\%}$ are doses covering 5% and 95% of the PTV, respectively.

For the rectum and bladder, the $V_{70\text{Gy}}$, $V_{50\text{Gy}}$, $V_{40\text{Gy}}$, $V_{20\text{Gy}}$, and the mean dose were compared between treatments. Additionally, the mean doses to the femoral heads and penile bulb, the integral dose, and MU values were compared for each set of plans.

Dosimetric analysis

For comparative purposes, the f-SA plans were used as the standard, and the average difference (D_{avg}) in the corresponding dosimetric parameter (for example, mean dose, $V_{70\text{Gy}}$, integral dose, and so on) between the f-SA and p-SA plans of the same case was calculated using equation 3.

$$D_{\text{avg}}(X) = \frac{1}{10} \sum_{n=1}^{10} \left[\frac{(f\text{-SA})_n - (p\text{-SA})_n}{(f\text{-SA})_n} \times 100 \right] \quad (3),$$

Where X is the corresponding dosimetric parameter in the f-SA and p-SA plans for the n^{th} case.

In equation 3, the D_{avg} is expressed as a percentage and averaged over all 10 cases in this study. For a given dosimetric parameter in equation 3, a positive D_{avg} implies a higher dosimetric value in the f-SA plans compared with the p-SA plans, and a negative D_{avg} implies a higher dosimetric value in the p-SA plans compared with the f-SA plans. The statistical analysis was performed using the

paired two-sided Student t test in a Microsoft Excel spreadsheet, and a P value < 0.05 was considered significant.

Results

Table 2 shows the results of the dosimetric parameters for the f-SA and p-SA plans, and the D_{avg} of dosimetric parameters of the PTV, rectum, bladder, femoral heads, penile bulb, the integral dose, and MUs are shown in **Figure 2**. The results presented in **Table 2** and **Figure 2** are averages from the 10 analyzed cases.

Patient characteristics

The median age of the 10 patients was 69 years (range, 58 – 82 years). Their Gleason scores ranged from 6 to 7, and their prostate-specific antigen (PSA) levels ranged from 1.8 ng/mL to 12.7 ng/mL. The clinical stages of the 10 cases ranged from T1a to T2a. The average PTV, the average volumes of the rectum, bladder, femoral heads, and penile bulb were $(125.3 \pm 14.6) \text{ cm}^3$ (range, $101.3 - 139.8 \text{ cm}^3$), $(86.0 \pm 31.4) \text{ cm}^3$ (range, $49.6 - 159.1 \text{ cm}^3$), $(171.9 \pm 86.9) \text{ cm}^3$ (range, $103.4 - 349.6 \text{ cm}^3$), $(379.7 \pm 71.2) \text{ cm}^3$ (range, $257.6 - 515.8 \text{ cm}^3$), and $(6.4 \pm 2.6) \text{ cm}^3$ (range, $3.9 - 13.4 \text{ cm}^3$), respectively.

Doses to the PTV

In comparison to the p-SA technique, the f-SA technique produced a higher minimum dose to the PTV, with a D_{avg} of 0.7%,

Table 2. Comparison of dosimetric parameters for the f-SA and p-SA plans in RapidArc planning for prostate cancer treatment

Structure	Parameter	f-SA	p-SA	P
PTV	Min dose (Gy)	73.5 ± 1.0	72.9 ± 1.0	0.131
	Mean dose (Gy)	80.9 ± 0.6	81.0 ± 0.3	0.791
	Max dose (Gy)	83.9 ± 0.6	84.4 ± 0.7	0.009
	CI	1.27 ± 0.05	1.26 ± 0.04	0.557
	HI	1.04 ± 0.01	1.04 ± 0.01	0.699
Rectum	Mean dose (Gy)	42.3 ± 7.4	38.1 ± 6.2	<0.001
	$V_{70\text{Gy}}$ (%)	21.4 ± 8.3	18.7 ± 4.0	0.135
	$V_{50\text{Gy}}$ (%)	48.3 ± 9.8	38.1 ± 7.7	<0.001
	$V_{40\text{Gy}}$ (%)	57.8 ± 10.4	48.1 ± 9.8	<0.001
	$V_{20\text{Gy}}$ (%)	67.6 ± 12.3	63.5 ± 11.9	0.002
Bladder	Mean dose (Gy)	36.7 ± 11.3	30.3 ± 8.8	<0.001
	$V_{70\text{Gy}}$ (%)	14.4 ± 7.7	12.7 ± 6.3	0.030
	$V_{50\text{Gy}}$ (%)	31.4 ± 15.0	23.1 ± 10.1	0.004
	$V_{40\text{Gy}}$ (%)	44.0 ± 18.1	30.6 ± 11.8	0.001
	$V_{20\text{Gy}}$ (%)	67.2 ± 22.1	54.5 ± 17.6	<0.001
Femoral heads	Mean dose (Gy)	13.7 ± 3.0	18.0 ± 3.4	0.001
Penile bulb	Mean dose (Gy)	22.7 ± 6.5	22.1 ± 5.8	0.166
Monitor unit (MUs)		475 ± 28	516 ± 35	0.028
Integral dose [$(\text{cm}^3 \cdot \text{Gy}) \times 10^6$]		1.1 ± 0.2	1.2 ± 0.2	<0.001

Min, minimum; Max, maximum; CI, conformity index; HI, homogeneity index; $V_{n\text{Gy}}$, percentage volume irradiated by n Gy or more of a certain structure. The values are presented as mean \pm standard deviation (SD) of the 10 analyzed cases. The P values were obtained from paired two-sided Student t tests; a P value < 0.05 was considered significant.

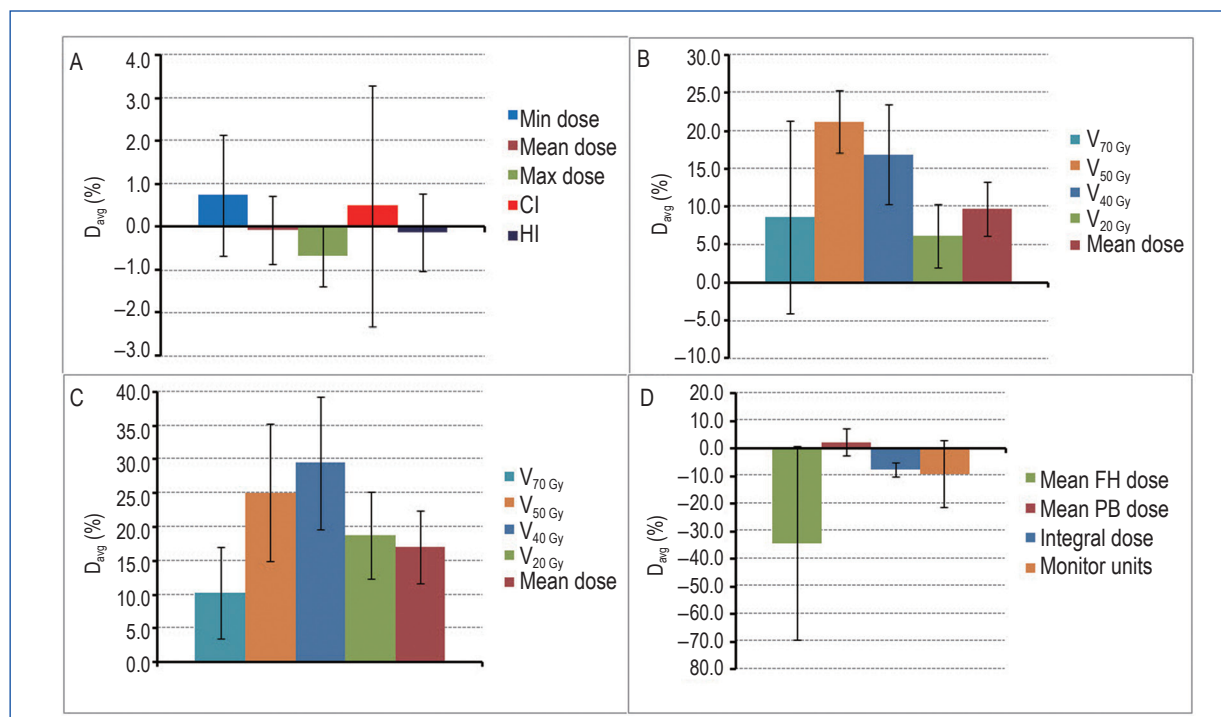


Figure 2. Average difference (D_{avg}) of dosimetric parameters between the f-SA and p-SA plans. A, the dose to the PTV, conformity index (CI), and homogeneity index (HI); B, the dose to the rectum; C, the dose to the bladder; and D, the doses to the femoral heads (FH) and penile bulb (PB), the integral dose, and monitor units. The error bars represent the standard deviations. The values are averaged over the 10 analyzed cases. The D_{avg} (%) is defined in equation 3 (Methods and Materials). $V_{n\text{Gy}}$, percentage volume irradiated by n Gy or more of a certain structure.

but lower mean and maximum doses to the PTV, with D_{avg} of 0.1% and 0.7%, respectively. Statistical significance was obtained for the maximum dose to the PTV ($P = 0.009$) but not for the minimum ($P = 0.131$) and mean doses to the PTV ($P = 0.791$).

Dose coverage and homogeneity of the PTV

The CI was slightly higher in the f-SA plans, indicating that the f-SA technique has the potential to produce less conformal plans than the p-SA technique; however, the D_{avg} was only 0.5% ($P = 0.557$). Both techniques produced an identical average HI value (1.04), and the D_{avg} was very small ($D_{avg} = -0.1\%$, $P = 0.699$).

Doses to OARs and MU difference

The dose to the rectum was always higher in the f-SA plans than in the p-SA plans. Specifically, the f-SA technique produced higher values of $V_{70\text{ Gy}}$ ($D_{avg} = 8.6\%$, $P = 0.135$), $V_{50\text{ Gy}}$ ($D_{avg} = 21.2\%$, $P < 0.001$), $V_{40\text{ Gy}}$ ($D_{avg} = 16.9\%$, $P < 0.001$), and $V_{20\text{ Gy}}$ ($D_{avg} = 6.1\%$, $P = 0.002$), and mean dose ($D_{avg} = 9.7\%$, $P < 0.001$).

Similar to dosimetric results of the rectum, the f-SA technique resulted in higher radiation exposure to the bladder, and the p-SA technique was better in sparing of the bladder, showing statistical significance at high, medium, and low dose levels. Specifically, the f-SA technique produced higher values of $V_{70\text{ Gy}}$ ($D_{avg} = 10.3\%$, $P =$

0.030), $V_{50\text{ Gy}}$ ($D_{avg} = 25.0\%$, $P = 0.004$), $V_{40\text{ Gy}}$ ($D_{avg} = 29.5\%$, $P = 0.001$), $V_{20\text{ Gy}}$ ($D_{avg} = 18.8\%$, $P < 0.001$), and mean dose ($D_{avg} = 17.0\%$, $P < 0.001$). In comparison to the f-SA plans, the dose to the femoral heads was significantly higher in the p-SA plans ($D_{avg} = 34.4\%$, $P = 0.001$). A cumulative DVH for case # 8 is presented in **Figure 3**, which clearly shows reduced doses to the bladder and rectum but an increased dose to the femoral heads from the p-SA technique compared with the f-SA technique for the same PTV coverage.

The p-SA technique also resulted in a greater number of MUs ($D_{avg} = 9.2\%$, $P = 0.028$) and a higher integral dose ($D_{avg} = 7.7\%$, $P < 0.001$). In contrast, the mean dose to the penile bulb was lower in the p-SA plans than in the f-SA plan ($D_{avg} = 2.2\%$, $P = 0.166$).

Discussion

In this study, we investigated the dosimetric quality of two treatment techniques (f-SA vs. p-SA) in RapidArc planning for the same PTV coverage and identical plan optimization parameters. The dosimetric analysis was performed for the PTV, rectum, bladder, femoral heads, and penile bulb from the DVHs generated in the Eclipse TPS. The dosimetric results obtained from both techniques were within the tolerance limits. The f-SA and p-SA plans had a D_{avg} of $\pm 1\%$ for the doses to the PTV, and there were no clear differences in dose homogeneity and plan conformity, as indicated by a small D_{avg} (within $\pm 0.5\%$). However, in comparison with the f-SA technique,

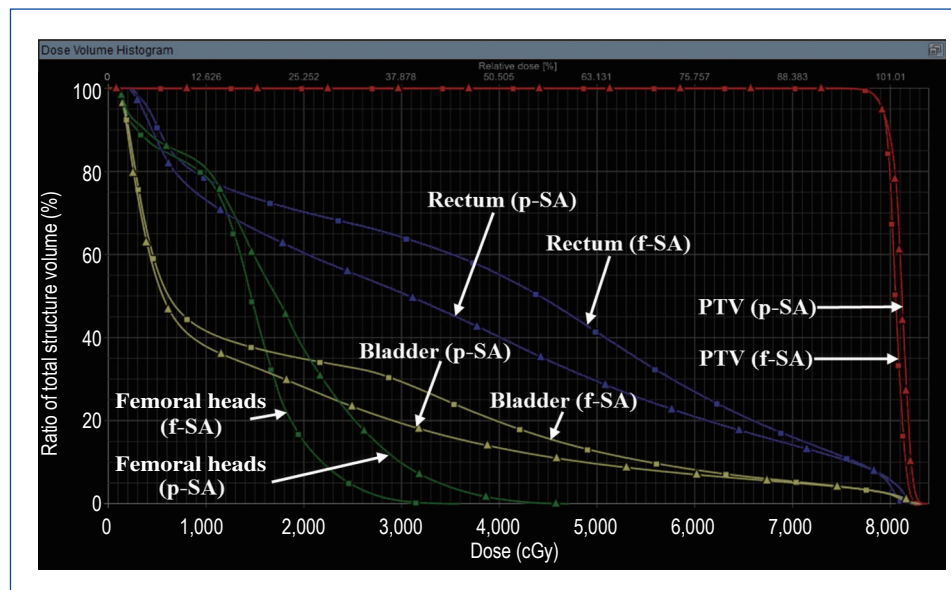


Figure 3. Dose-volume histogram of case # 8 for organs at risk, such as the rectum, bladder, and femoral heads, and the PTV created by the f-SA and p-SA techniques in RapidArc planning for prostate cancer treatment.

the p-SA technique was better in sparing of the rectum and bladder at high, medium, and low dose levels in this study. This was mainly due to the use of anterior and posterior avoidance sectors to prevent the direct beam entrance to certain parts of the bladder and rectum, respectively, thus resulting into lower doses to the bladder and rectum. The D_{avg} for the rectum ranged from 6.1% to 21.2%, whereas the D_{avg} for the bladder ranged from 10.3% to 29.5%. For both the rectum and bladder, a greater difference between f-SA and p-SA plans was observed at the medium dose levels of V_{40Gy} and V_{50Gy} (D_{avg} : 16.9% to 29.5%) when compared with the high dose level at V_{70Gy} (D_{avg} : 8.6% to 10.3%) and low dose level at V_{20Gy} (D_{avg} : 6.1% to 18.8%). In contrast to the dosimetric results for the rectum and bladder, the femoral heads in the p-SA plans received a higher mean dose mainly due to the spread of lateral dose distributions by the anterior and posterior avoidance sectors used in the p-SA technique.

Although we could not find data in the literature that were suitable for direct comparison against our dosimetric data for the f-SA and p-SA techniques in RapidArc planning, it is relevant to mention studies performed by other researchers on RapidArc planning for prostate cancer treatment. Yoo *et al.*^[8] have investigated the dosimetric impact of SA and DA techniques on prostate cancer involving seminal vesicles and lymph nodes. They reported that the DA technique produced a lower maximum dose to the PTV as well as lower doses to the rectum and bladder compared with the SA technique^[8]. In contrast, Sze *et al.*^[9] have shown that the SA technique produced a lower dose at a high dose level (V_{70Gy}) as well as at a low dose level (V_{20Gy}) but a higher dose at a medium dose level (V_{40Gy}) for the bladder when compared with the DA technique. Furthermore, Sze *et al.*^[9] have found that the DA technique produced lower doses to the rectum compared to the SA technique. In contrast, Guckenberger *et al.*^[10] have shown that the DA technique yielded a higher dose to the rectum compared with the SA technique, whereas Wolff *et al.*^[11] have found no significant difference in plan quality between the DA and SA plans.

Despite the inconsistencies observed among the results of previous studies^[8-11], a common finding was that SA achieved better treatment efficiency with dosimetric outcome within tolerable limits. The dosimetric results of the p-SA technique found in this study suggest that the p-SA could provide an alternative option for clinics that currently use the f-SA technique in RapidArc planning for prostate cancer treatment. The p-SA technique showed the possibility of reducing radiation exposure to the rectum, bladder, and penile bulb without compromising the plan conformity and target homogeneity; however, a higher dose to the femoral head and higher values of MUs and integral dose from p-SA technique should also be noted. Furthermore, the dosimetric results presented in this study showed that both the f-SA and p-SA techniques can meet the Quantitative Analyses of Normal Tissue Effects in the Clinic (QUANTEC) criteria^[12]. Although the p-SA technique showed the possibility of dose escalation for prostate cancer patients by reducing the doses to the rectum and bladder, clinical data, such as normal tissue toxicities, associated with different VMAT planning techniques remain to be reported.

One limitation of this study was that we used the same plan optimization parameters (**Table 1**), which were based on the experience of a single treatment planner. During the plan optimization process in Eclipse TPS, a treatment planner has the flexibility of adjusting the plan optimization parameters to generate an optimum treatment plan. For example, this study showed that the p-SA plans provided a slightly higher dose to the femoral heads, but the stricter dose constraints placed on the femoral heads can force the TPS to reduce the dose to the femoral heads, decrease dose homogeneity across the PTV, and reduce target coverage. Thus, a different set of plan optimization parameters may produce slightly different dosimetric results. We also did not investigate the dosimetric quality of the DA technique. A DA plan generally has more control points and could provide a higher degree of modulation, which may result in better plan quality. In the future, we aim to perform a dosimetric and

radiobiological modeling study to compare f-SA and p-SA techniques with DA techniques.

Several researchers have documented the inadequacy of AAA to calculate the dose accurately when inhomogeneous media are involved along the photon beam path^[13-17]. Because the same algorithm was used for all dose calculations in this study, the limitation of AAA in dealing with inhomogeneities did not influence the dosimetric comparison between the f-SA and p-SA plans; however, the use of a more accurate dose calculation algorithm, such as Acuros XB (available in the Eclipse TPS), could further improve the dose calculation accuracy of the dosimetric results^[15-17].

References

- [1] Howlader N, Noone AM, Krapcho M, et al. SEER cancer statistics Review. National Cancer Institute, Bethesda, MD, 2009.
- [2] Ling CC, Zhang P, Archambault Y, et al. Commissioning and quality assurance of RapidArc radiotherapy delivery system. *Int J Radiat Oncol Biol Phys*, 2008,72:575–581.
- [3] Otto K. Volumetric modulated arc therapy: IMRT in a single gantry arc. *Med Phys*, 2008, 35: 310–317.
- [4] Rana SB. Volumetric intensity modulated arc therapy in lung cancer: current literature review. *Clin Cancer Investig J*, 2013, 2:9–13
- [5] Zhang P, Happersett L, Hunt M, et al. Volumetric modulated arc therapy: planning and evaluation for prostate cancer cases. *Int J Radiat Oncol Biol Phys*, 2010, 76:1456–1462.
- [6] Palma D, Vollans E, James K, et al. Volumetric modulated arc therapy for delivery of prostate radiotherapy: comparison with intensity-modulated radiotherapy and three-dimensional conformal radiotherapy. *Int J Radiat Oncol Biol Phys*, 2008, 72:996–1001.
- [7] Shaffer R, Morris WJ, Moiseenko V, et al. Volumetric modulated Arc therapy and conventional intensity-modulated radiotherapy for simultaneous maximal intra prostatic boost: a planning comparison study. *Clin Oncol (R Coll Radiol)*, 2009, 21:401–407.
- [8] Yoo S, Wu QJ, Lee WR, et al. Radiotherapy treatment plans with RapidArc for prostate cancer involving seminal vesicles and lymph nodes. *Int J Radiat Oncol Biol Phys*, 2010, 76:935–942.
- [9] Sze HC, Lee MC, Hung WM, et al. RapidArc radiotherapy planning for prostate cancer: single-arc and double-arc techniques vs. intensity-modulated radiotherapy. *Med Dosim*, 2012, 37:87–91.
- [10] Guckenberger M, Richter A, Krieger T, et al. Is a single arc sufficient in volumetric-modulated arc therapy (VMAT) for complex-shaped target volumes? *Radiother Oncol*, 2009, 93: 259–265.
- [11] Wolff D, Stieler F, Welzel G, et al. Volumetric modulated arc therapy (VMAT) vs. serial tomotherapy, step-and-shoot IMRT and 3D-conformal RT for treatment of prostate cancer. *Radiother Oncol*, 2009, 93:226–233.
- [12] Marks LB, Yorke ED, Jackson A, et al. Use of normal tissue complication probability models in the clinic. *Int J Radiat Oncol Biol Phys*, 2010, 76(3 Suppl):S10–9.
- [13] Robinson D. Inhomogeneity correction and the analytic anisotropic algorithm. *J Appl Clin Med Phys*, 2008; 9: 112–122.
- [14] Rana SB. Dose prediction accuracy of anisotropic analytical algorithm and pencil beam convolution algorithm beyond high density heterogeneity interface. *South Asian J Cancer*, 2013, 2:26–30.
- [15] Bush K, Gagne IM, Zavgorodni S, et al. Dosimetric validation of Acuros XB with Monte Carlo methods for photon dose calculations. *Med Phys*, 2011, 38:2208–2221.
- [16] Rana S, Rogers K. Dosimetric evaluation of Acuros XB dose calculation algorithm with measurements in predicting doses beyond different air gap thickness for smaller and larger field sizes. *J Med Phys*, 2013, 38:9–14.
- [17] Han T, Mourtada F, Kisling K, et al. Experimental validation of deterministic Acuros XB algorithm for IMRT and VMAT dose calculations with the Radiological Physics Center's head and neck phantom. *Med Phys*, 2012, 39:2193–2202.

Conclusions

The preliminary results presented in this study showed that it is feasible to use the p-SA technique in RapidArc planning for prostate cancer treatment. For the same PTV coverage and identical plan optimization parameters, the p-SA technique delivers a higher dose to the femoral heads but reduces the doses to the rectum, bladder, and penile bulb without compromising the plan conformity and target homogeneity when compared with the f-SA technique.

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