Original Article

Investigating VMAT planning technique to reduce rectal and bladder dose in prostate cancer treatment plans

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ABSTRACT

Background: RapidArc is a volumetric modulated arc therapy (VMAT) technique that can deliver conformal dose distribution to the target while minimizing dose to critical structures. The main purpose of this study was to compare dosimetric quality of full double arc (full DA), full single arc (full SA), and partial double arc (partial DA) techniques in RapidArc planning of prostate cancer. **Materials and Methods:** Twelve cases of prostate cancer involving seminal vesicles were selected for this retrospective study. For each case, RapidArc plans were created using full DA (two full arcs), full SA (one full arc), and partial DA (two partial arcs with anterior and posterior avoidance sectors) techniques. For planning target volume (PTV), the maximum and mean doses, conformity, and inhomogeneity indices were evaluated. For bladder and rectum, volumes that received 70, 50, 40, and 20 Gy (V_{70Gy}, V_{50Gy}, V_{40Gy} and V_{20Gy}, respectively), and mean dose were compared. For femoral heads, V_{40Gy}, V_{20Gy}, and mean dose were evaluated. Additionally, an integral dose and monitor units (MUs) were compared for each treatment plan. **Results:** In comparison to full DA and full SA techniques, the partial DA technique was better in sparing of rectum and bladder but delivered higher femoral head dose, which was nonetheless within the planning criteria. No clear dosimetric differences were found between full DA and partial DA plans for dose conformity and target homogeneity. The number of MUs and integral dose were largest with the partial DA technique and lowest with the full SA technique. **Conclusion:** The partial DA technique provides an alternative RapidArc planning approach for low risk prostate cancer.

Key words: Avoidance sector, dosimetric, full arc, partial arc, prostate cancer, RapidArc

INTRODUCTION

Prostate adenocarcinoma is the second most commonly male diagnosed cancer in America after skin cancer.[1] External beam radiation therapy (EBRT) has played an important role as a treatment option over the years. The developments in EBRT such as intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) allow the delivery of conformal dose distribution to the target while minimizing the dose to the critical structures.[2-4] In recent years, the VMAT has become the preferred option over IMRT for prostate cancer treatment since VMAT utilizes lower number of monitor units (MUs) in treatment, while achieving IMRT quality dose distributions.[2-4] RapidArc (Varian Medical Systems, Palo Alto, CA) is one of such VMAT techniques that delivers modulated radiation beams with simultaneous adjustment of multileaf collimator field aperture, dose rate, and gantry rotation speed.[2-4]

Several studies have reported clinical RapidArc dosimetric comparisons for prostate,[5-13] but the results were inconsistent mainly due to variations found in terms of target shape, target volume margins, planning techniques, objectives, etc., Furthermore, no investigation has been performed in the concept of utilizing partial arcs that consists of anterior and posterior avoidance sectors in prostate cancer RapidArc plans. Currently, a prostate cancer RapidArc plan with two full arcs is considered to be the standard plan at West Hills Radiation Therapy Center, Vantage Oncology, California, `and it is essential to further explore the RapidArc planning techniques in order

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to improve the quality of prostate cancer treatment plans. The main purposes of this study were to (1) investigate the possibility of reducing rectal and bladder dose using partial double arc (partial DA) technique, and (2) compare the dosimetric results obtained from the full single arc (full SA) and full double arc (full DA) techniques.

MATERIALS AND METHODS

Computed tomography simulation and contouring

Twelve low risk prostate cancer cases were selected for this retrospective study, and all cases were treated at West Hills Radiation Therapy Center, Vantage Oncology, California, USA. Patients were immobilized in a Vac-Lok system (CIVCO Medical Solutions, Kalona, Iowa) and were instructed to maintain a full bladder during the CT simulation process. The CT images were acquired with 512 × 512 pixels at 0.25 cm slice spacing using GE LightSpeed CT Scanner (GE Healthcare, Milwaukee, WI). Digital Imaging and Communications in Medicine (DICOM) CT images were transferred to the Varian Eclipse treatment planning system (TPS) for planning preparation. The following volumes of interest were created in each axial CT slice: (1) Planning target volume (PTV) from a 5 mm wide isotropic expansion of clinical target volume (CTV) comprised of prostate and seminal vesicles, and (2) organs at risk (OARs), that is, rectum, bladder, and femoral heads.

Planning, optimization, calculation, and normalization

The planning parameters for all RapidArc plans were set up using Varian Standard Scale in the Eclipse TPS (version 11.0.21) utilizing Varian Clinac ix 6 MV beams (Varian Medical Systems, Palo Alto, CA). Three RapidArc plans were created in each case and isocenter of the plans was placed at center of the PTV. Set A: The full DA plan was created using two arcs; first full arc in an anticlockwise direction (arc angle: 1°→359°; collimator angle: 170°) and the second full arc in a clockwise direction (arc angle: 359°→1°; collimator angle: 190°). [Figure 1] The Beam's eye view graphics in the Eclipse TPS was used to better define the field sizes of each coplanar arc according to the location of the PTV and OARs with an objective of achieving maximal PTV coverage and minimal OARs dose [Figure 2]. Set B: The full SA plan was created using a single full arc in an anticlockwise direction (arc angle: 1°→359°; collimator angle: 170°). The field sizes of a single arc in the full SA plan were same as the field sizes of the first full arc in the full DA plan. Set C: The partial DA plan was created using identical planning parameters (e.g., field sizes and collimator angle) of the full DA plan except for the length of gantry rotations. Specifically, each partial arc in the partial DA plan consisted of an anterior avoidance sector of 30° and a posterior avoidance sector of 60° [Figure 1].

The PTV prescription dose was 79.2 Gy with daily dose of 1.8 Gy. The dose constraints to the OARs are summarized in Table 1. These dose constraints were determined based on Radiation Therapy Oncology Group-0815 guidelines. All plans were generated using Varian Eclipse Progressive Resolution Optimizer (version 11.0.21), and the volumetric dose optimization method followed the same systematic strategy regarding the optimization constraints and weightings [Table 2]. In order to make fair comparisons among three sets of plans, no modifications of dose-volume constraints and weightings were made during the optimization process of the plan.

Dose calculation, normalization, and evaluation

All optimized RapidArc plans were calculated with an anisotropic analytical algorithm, version 11.0.21, in the Eclipse TPS, and the dose calculation grid was set to 2.5 mm for all cases. The calculated plans were then normalized such that 100% of prescribed dose covered at least 95% of the PTV volume. The dose-volumetric analysis was performed by using dose-volume histograms (DVHs) of 12 prostate cases. For the PTV, the maximum dose (D_{max}), mean dose (D_{mean}), conformity index (CI) (defined in equation 1), and inhomogeneity index (II) (defined in equation 2) were compared.

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

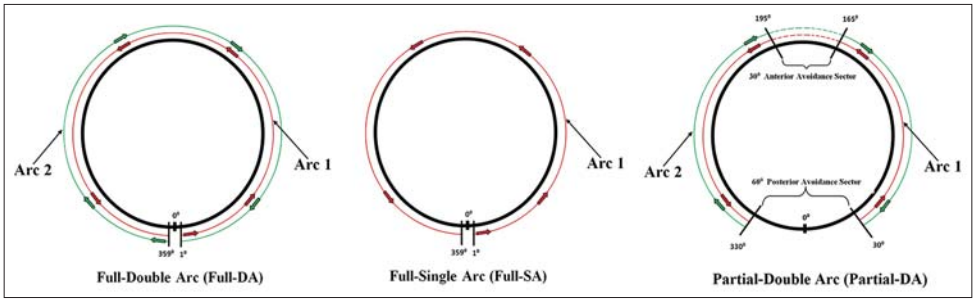

Figure 1: Schematic of full double arc, full single arc, and partial DA techniques for RapidArc planning in eclipse treatment planning system (Varian standard scale)

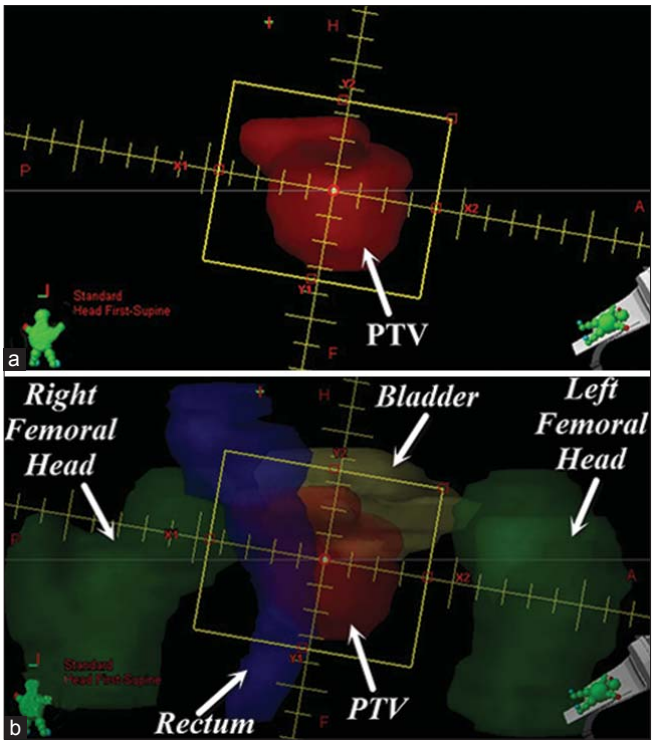

Figure 2: Beam's eye view at the gantry angle 315° and collimator angle 190° (Varian standard scale) for (a) planning target volume and (b) bladder, rectum, femoral heads, and PTV

Table 1: Dose specifications for rectum, bladder, and femoral heads

Normal organ limit[a]	$D_{15\%}$ (Gy)	$D_{25\%}$ (Gy)	$D_{35\%}$ (Gy)	$D_{50\%}$ (Gy)
Rectum	<75	<70	<65	<60
Bladder	<80	<75	<70	<65
Femoral heads	Mean dose <45			

[a]Normal organ limit refers to the volume of that organ that should not exceed the dose limit. $D_{x\%}$: Dose received by x% of total organs at risk volume, where x%=15, 25, 35, and 50

Table 2: Dose-volume constraints and weightings used for optimization for prostate plans in RapidArc planning using full DA, full SA, and partial DA techniques

Structure	Objective	Volume (%)	Dose (cGy)	Weighting
PTV	Upper	0	8150	250
	Lower	100	8050	250
Rectum	Upper	0	7800	85
	Upper	15	7000	85
	Upper	35	6000	85
	Upper	50	5000	85
Bladder	Upper	0	7800	80
	Upper	15	7500	80
	Upper	35	6500	80
	Upper	50	6000	80
Femoral heads	Upper	0	5500	80
	Upper	10	5000	80

DA: Double arc, SA: Single arc, PTV: Planning target volume

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

$$II = \frac{D_{5\%} - D_{95\%}}{D_{mean}} \quad (2)$$

Where, $D_{5\%}$ and $D_{95\%}$ are doses at 5 and 95% of the PTV, respectively, and D_{mean} is the mean PTV dose.

To evaluate irradiated volumes of the bladder and rectum, the volumes that received 70, 50, 40, and 20 Gy (V_{70Gy}, V_{50Gy}, V_{40Gy} and V_{20Gy}, respectively) as well as D_{mean} were compared. For the femoral heads, the V_{40Gy}, V_{20Gy}, and D_{mean} were evaluated. Additionally, the MU values and normal tissue integral dose (NTID) were acquired for each treatment plan. The NTID (in units of Gy cc) was defined as absorbed dose integrated over voxels in the entire area excluding PTV. A paired two-sided Student's *t*-test was used to calculate the statistical difference of dose-volumetric results between the full DA and partial DA plans, full DA and full SA plans, and full SA and partial DA plans. A *P* value of less than 0.05 (i.e., $P < 0.05$) was considered to be statistically significant.

RESULTS

The average volumes of the PTV, rectum, bladder, and femoral heads were 128.4 ± 32.0 cc (range: 77-210.3 cc), 88.7 ± 29.3 cc (range: 49.6-159.1 cc), 179.2 ± 86.8 cc (range: 103.4-349.6 cc), and 389.0 ± 72.4 cc (range: 257.6-515.8 cc), respectively. Table 3 summarizes results of dosimetric parameters for full DA, full SA, and partial DA plans and the values are averaged over the 12 analyzed cases.

PTV

The D_{max} and D_{mean} to the PTV were slightly higher in full SA plans than in full DA plans (D_{max}: 83.87 vs 83.05 Gy, $P = 0.00001$; D_{mean}: 80.87 vs 80.35 Gy, $P = 0.00494$) and partial DA plans (D_{max}: 83.87 vs 83.07 Gy, $P = 0.00184$; D_{mean}: 80.87 vs 80.43 Gy, $P = 0.02980$), but the differences were less than 1%. The differences of D_{max} and D_{mean} to PTV between full DA and partial DA plans were less than 0.1% ($P = 0.92411$ for D_{max} and $P = 0.04300$ for D_{mean}).

The CI value was higher (higher CI means less conformal plans) in full SA plans compared with CI values in full DA plans (1.27 vs 1.24, $P = 0.04034$) and partial DA plans (1.27 vs 1.24, $P = 0.03754$). The full DA and partial DA plans produced the same CI (1.24 vs 1.24, $P = 0.96037$). Similar trend was obtained in the target II. Specifically, full SA plans showed slightly higher target inhomogeneity compared with full DA (0.04 vs 0.03, $P = 0.00103$) and partial DA plans (0.04 vs 0.03, $P = 0.01211$). The full DA and partial DA plans produced identical target inhomogeneity (0.03 vs. 0.03, $P = 0.02795$).

Rectum

The dose to the rectum was always highest in full SA plans and lowest in partial DA plans for all evaluated dose-volume parameters in this study. Specifically, rectal volume of partial DA plans that received 70, 50, 40, and 20 Gy were smaller than those of full DA plans (V_{70Gy}: 16.55 vs 16.94%, $P = 0.18347$; V_{50Gy}: 36.19 vs 43.18%, $P = 0.01357$; V_{40Gy}: 46.48 vs

Table 3: Comparison of dosimetric parameters for the full DA, full SA, and partial DA plans

	Full-DA (Avg.±SD)	Full-SA (Avg.±SD)	Partial-DA (Avg.±SD)	*P* value (full DA vs. full SA)	*P* value (full DA vs. partial DA)	*P* value (full SA vs. partial DA)
PTV						
D_{max} (Gy)	83.05±0.35	83.87±0.57	83.07±0.43	0.00001	0.92411	0.00184
D_{mean} (Gy)	80.35±0.14	80.87±0.59	80.43±0.16	0.00494	0.043	0.0298
CI	1.24±0.03	1.27±0.05	1.24±0.03	0.04034	0.96037	0.03754
II	0.03±0.00	0.04±0.01	0.03±0.00	0.00103	0.02795	0.01211
Rectum						
D_{mean} (Gy)	40.23±8.47	41.22±9.23	36.82±7.79	0.02092	0.00002	0.00002
V_{70Gy} (%)	16.94±5.22	19.99±8.29	16.55±4.66	0.02155	0.18347	0.01997
V_{50Gy} (%)	43.18±13.82	47.08±12.11	36.19±9.07	0.10202	0.01357	0.00001
V_{40Gy} (%)	56.42±13.58	56.86±13.72	46.48±11.25	0.58216	0.00006	0.00006
V_{20Gy} (%)	66.52±15.10	66.61±14.99	61.66±19.31	0.6181	0.02801	0.03022
Bladder						
D_{mean} (Gy)	34.49±12.40	35.12±12.94	28.97±9.94	0.03795	0.00028	0.00046
V_{70Gy} (%)	12.66±6.84	13.25±7.74	11.42±6.05	0.21338	0.00189	0.02425
V_{50Gy} (%)	27.72±13.17	29.55±15.37	21.18±9.75	0.04342	0.0011	0.00329
V_{40Gy} (%)	40.53±18.52	41.82±19.38	28.94±12.40	0.01053	0.00135	0.00098
V_{20Gy} (%)	65.04±26.81	65.10±26.44	53.03±20.62	0.85957	0.00053	0.00039
Femoral heads						
D_{mean} (Gy)	13.66±2.82	13.59±3.34	17.46±4.19	0.91328	0.00001	0.0033
V_{40Gy} (%)	0.20±0.40	0.54±1.08	2.80±5.28	0.13189	0.10433	0.15116
V_{20Gy} (%)	19.21±12.50	19.76±14.26	36.05±17.72	0.87282	0	0.00029
Monitor unit (MUs)	494±25	475±27	535±28	0.00069	0.00541	0.00059
NTID (10^5 Gy cc)	1.13±0.28	1.12±0.27	1.19±0.29	0.45431	0.00007	0.00002

DA: Double arc, SA: Single Arc, Avg: Average, SD: Standard deviation, PTV: Planning target volume, D_{max}: Maximum dose, D_{mean}: Mean dose, D_5%: Dose received by the 5% volume of the PTV, V_{95}%: Volume of the isodose cloud receiving at least 95% of the prescription dose, V_{nGy}: Percentage volume irradiated by n Gy or more of a certain structure, CI: Conformity index, II: Inhomogeneity index, MUs: Monitor units, NTID: Normal tissue integral dose. (The values are averaged over the 12 analyzed cases. The *P* values were obtained from paired two-sided Student's *t* test, and a *P* value of less than 0.05 (i.e., $P<0.05$) was considered to be statistically significant)

56.42%, $P = 0.00006$; and V_{20Gy}: 61.66 vs 66.52%, $P = 0.02801$). The full DA plans produced lower dose to rectum compared with full SA plans ($V_{70Gy} = 19.99\%$, $P = 0.02155$; $V_{50Gy} = 47.08\%$, $P = 0.10202$; $V_{40Gy} = 56.86\%$, $P = 0.58216$; and $V_{20Gy} = 66.61\%$, $P = 0.61810$). The mean dose to rectum was lower in partial DA plans compared with full DA plans (36.82 vs 40.23 Gy, $P = 0.00002$) and full SA plans (36.82 vs 41.22 Gy, $P = 0.00002$).

Bladder

The trend of delivering higher dose from full SA technique and lower dose from partial DA technique continued for bladder too. Specifically, partial DA plans produced lower V_{70Gy}, V_{50Gy}, V_{40Gy}, and V_{20Gy} compared with full DA plans (V_{70Gy}: 11.42 vs 12.66%, $P = 0.00189$; V_{50Gy}: 21.18 vs 27.72%, $P = 0.00110$; V_{40Gy}: 28.94 vs 40.53%, $P = 0.00135$, and V_{20Gy}: 53.03% vs 65.04%, $P = 0.00053$). Furthermore, full DA plans produced lower dose to bladder compared with full SA plans ($V_{70Gy} = 13.25\%$, $P = 0.21338$; $V_{50Gy} = 29.55\%$, $P = 0.04342$; $V_{40Gy} = 41.82\%$, $P = 0.01053$; and $V_{20Gy} = 65.10\%$, $P = 0.85957$). The full SA plans produced highest D_{mean} compared with full DA plans (35.12 vs 34.49 Gy, $P = 0.03795$) and partial DA plans (35.12 Gy vs 28.97 Gy, $P = 0.00046$).

Femoral heads

The dose to femoral heads was always higher in partial-DA plans. Specifically, the femoral heads volume of partial DA plans that received 40 and 20 Gy were higher than those of full DA plans (V_{40Gy}: 2.80 vs 0.20%, $P = 0.10433$ and V_{20Gy}: 36.05 vs 19.21%, $P = 0.00000$). Furthermore, full DA plans produced higher dose to femoral heads compared to full SA plans ($V_{40Gy} = 0.54.82\%$, $P = 0.13189$ and $V_{20Gy} = 19.76\%$, $P = 0.87282$). The D_{mean} was larger in the partial DA plans compared with full DA plans (17.46 vs 13.66 Gy, $P = 0.00001$) and full SA plans (17.46 vs 13.59 Gy, $P = 0.00330$).

Monitor units and normal tissue dose

The average value of MUs of partial DA plans was higher than that of full DA (535 vs 494 MUs, $P = 0.00541$) and full SA plans (535 vs 475 MUs, $P = 0.00059$). The NTID was lowest in full SA plans (1.12×10^5 Gy cc) and highest in partial DA plans (1.19×10^5 Gy cc).

DISCUSSION

In this study, we compared the RapidArc planning of three techniques (full DA, full SA, and partial DA) in the treatment of low risk prostate cancer, and the dosimetric results from all three techniques were clinically acceptable. The full DA and partial DA techniques produced more conformal and less heterogeneous plans as well as better rectal and bladder sparing compared with full SA technique. There were no clear dosimetric differences between full DA and partial DA plans for dose conformity and target heterogeneity; however, the partial-DA technique was superior in sparing of rectum and bladder compared with full DA technique. This result was explained by the fact that anterior and posterior avoidance sectors in partial DA technique avoided direct beam entrance to certain part of bladder and rectum, respectively; thus resulting lower doses to bladder and

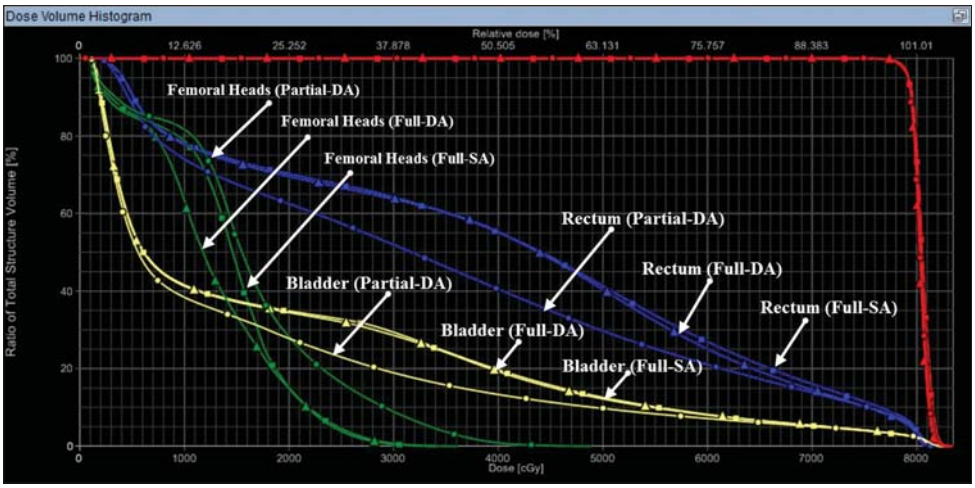

Figure 3: Dose-volume histogram of case # 10 for organs at risk (OAR; rectum, bladder, femoral heads) created by full DA, full SA and partial DA techniques in Rapid Arc planning of prostate cancer (PTV is not labeled). OARs: Organs at Risk, Full-DA: Full double arc, Full-SA: Full single arc, Partial-DA: Partial-double arc, PTV: Planning target volume

rectum. The higher femoral head doses in partial DA plans can be understood in the same context. The use of anterior and posterior avoidance sectors caused dose distributions to spread out laterally towards femoral heads; however, the dose received by femoral heads using partial DA technique was still found to be below our planning criteria. Figure 3 compares the DVH of bladder, rectum, and femoral heads of case # 10 for full DA, full SA, and partial DA techniques in RapidArc planning of prostate cancer.

Similar to our PTV dosimetric results, Sze *et al*.,[6] reported that DA technique produced lower target dose (D_{max} and D_{mean}) and more conformal and homogenous plans compared to SA technique for prostate cancer involving seminal vesicles. The study by Sze *et al*.,[6] also showed that dose to rectum was higher at V_{70Gy}, V_{40Gy}, and V_{20Gy} using SA than DA. These rectum dosimetric results from Sze *et al*.,[6] agreed with our results as DA techniques were better at sparing rectum at all dose levels (V_{70Gy}, V_{50Gy}, V_{40Gy}, V_{20Gy}, and D_{mean}) compared with SA technique. Furthermore, for femoral heads, our findings are in agreement with Sze *et al*.,[6] who reported higher dose in DA plans than in SA plans.

Our findings also agreed with those reported by Yoo *et al*.,[7] who conducted dosimetric comparison in prostate cancer involving seminal vesicles and lymph nodes. In that study, Yoo *et al*.,[7] reported that SA technique produced higher D_{max} to PTV, higher D_{mean} and V_{65Gy} to bladder, and higher D_{mean} and V_{70Gy} to rectum when compared with DA technique. Furthermore, Yoo *et al*.,[7] also showed higher target heterogeneity and less dose conformity in SA plans than in DA plans. These results from Yoo *et al*.,[7] further validated the findings in our study.

However, we have also noticed the inconsistency between the results of our study and previous studies that compared dosimetric results from DA and SA techniques in prostate cancer.[6,11,12] For example, Sze *et al*.,[6] showed that SA technique produced smaller values for V_{70Gy} and V_{20Gy}, but higher V_{40Gy} for bladder when compared with DA technique. In our study, the DA techniques always produced lower doses to the bladder. The major difference between our study and theirs is that we used two full arcs DA technique, whereas their studies[6] used one full arc and a partial arc in DA technique. The study by Guckenberger *et al*.,[11] showed that DA technique yielded higher dose to rectum compared with SA technique, whereas Wolff *et al*.,[12] found no significant difference in plan quality between DA and SA plans. Some of the reasons for such inconsistent dosimetric outcome may be due to different factors such as optimization algorithm, dose-volume optimization constraints and weightings, target volume definitions, PTV margins, planning parameters and strategies, dose calculation algorithm, etc.

The partial DA approach demonstrated in this study showed the possibility of reducing radiation exposure to rectum and bladder at high, medium, and low dose levels without compromising the plan conformity and target homogeneity. However, the partial DA technique yielded higher femoral head dose; thus, a clinician needs to make a decision about the tradeoff between sparing of rectum and bladder vs. femoral heads based on clinical needs.

CONCLUSION

The preliminary results from this retrospective study showed that DA techniques produced more conformal and homogenous plans as well as better rectal and bladder sparing compared with full SA technique. The femoral head dose was comparable in full DA and full SA plans. The partial DA technique was superior in sparing of the

rectum and bladder but delivered higher dose to femoral heads compared with full DA technique. There were no clear dosimetric differences between full DA and partial DA plans for dose conformity and target heterogeneity. The number of MUs and integral dose were largest with partial DA technique and lowest with full SA technique. The partial DA technique provides an alternative RapidArc planning approach for low risk prostate cancer.

REFERENCES

1. Howlader N, Noone AM, Krapcho M, Neyman N, Aminou R, Altekruse SF, *et al*. SEER Cancer Statistics Review. Bethesda, MD: National Cancer Institute; 2009.
2. Otto K. Volumetric modulated arc therapy: IMRT in a single gantry arc. Med Phys 2008;35:310-7.
3. Ling CC, Zhang P, Archambault Y, Bocanek J, Tang G, Losasso T. Commissioning and quality assurance of RapidArc radiotherapy delivery system. Int J Radiat Oncol Biol Phys 2008;72:575-81.
4. Tang G, Earl MA, Luan S, Wang C, Mohiuddin MM, Yu CX. Comparing radiation treatments using intensity-modulated beams, multiple arcs, and single arcs. Int J Radiat Oncol Biol Phys 2010;76:1554-62.
5. Palma D, Vollans E, James K, Nakano S, Moiseenko V, Shaffer R, *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.
6. Sze HC, Lee MC, Hung WM, Yau TK, Lee AW. RapidArc radiotherapy planning for prostate cancer: Single-arc and double-arc techniques vs. intensity-modulated radiotherapy. Med Dosim 2012;37:87-91.
7. Yoo S, Wu QJ, Lee WR, Yin FF. Radiotherapy treatment plans with RapidArc for prostate cancer involving seminal vesicles and lymph nodes. Int J Radiat Oncol Biol Phys 2010;76:935-42.
8. Zhang P, Happersett L, Hunt M, Jackson A, Zelefsky M, Mageras G. Volumetric modulated arc therapy: Planning and evaluation for prostate cancer cases. Int J Radiat Oncol Biol Phys 2010;76:1456-62.
9. Betzel GT, Yi BY, Niu Y, Yu CX. Is RapidArc more susceptible to delivery uncertainties than dynamic IMRT? Med Phys 2012;39:5882-90.
10. Kjaer-Kristoffersen F, Ohlhues L, Medin J, Korreman S. RapidArc volumetric modulated therapy planning for prostate cancer patients. Acta Oncol 2009;48:227-32.
11. Guckenberger M, Richter A, Krieger T, Wilbert J, Baier K, Flentje M. Is a single arc sufficient in volumetric-modulated arc therapy (VMAT) for complex-shaped target volumes? Radiother Oncol 2009;93:259-65.
12. Wolff D, Stieler F, Welzel G, Lorenz F, Abo-Madyan Y, Mai S, *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;93:226-33.
13. Shaffer R, Morris WJ, Moiseenko V, Welsh M, Crumley C, Nakano S, *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;21:401-7.

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