Original Article

An investigation of the dose distribution effect related with collimator angle in volumetric arc therapy of prostate cancer

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ABSTRACT

To investigate the dose-volume variations of planning target volume (PTV) and organ at risks (OARs) in eleven prostate cancer patients planned with single and double arc volumetric modulated arc therapy (VMAT) when varying collimator angle. Single and double arc VMAT treatment plans were created using Monaco5.0® with collimator angle set to 0°. All plans were normalized 7600 cGy dose to the 95% of clinical target volume (CTV) volume. The single arc VMAT plans were reoptimized with different collimator angles (0°, 15°, 30°, 45°, 60°, 75°, and 90°), and for double arc VMAT plans (0–0°, 15°–345, 30–330°, 45–315°, 60–300°, 75–285°, 90–270°) using the same optimization parameters. For the comparison the parameters of heterogeneity index (HI), dose-volume histogram and minimum dose to the 95% of PTV volume (D95 PTV) calculated and analyzed. The best plans were verified using 2 dimensional ion chamber array IBA Matrixx® and three-dimensional IBA Compass® program. The comparison between calculation and measurement were made by the γ-index (3%/3 mm) analysis. A higher D95 (PTV) were found for single arc VMAT with 15° collimator angle. For double arc, VMAT with 60–300° and 75–285° collimator angles. However, lower rectum doses obtained for 75–285° collimator angles. There was no significant dose difference, based on other OARs which are bladder and femur head. When we compared single and double arc VMAT's D95 (PTV), we determined 2.44% high coverage and lower HI with double arc VMAT. All plans passed the γ-index (3%/3 mm) analysis with more than 97% of the points and we had an average γ-index for CTV 0.36, for PTV 0.32 with double arc VMAT. These results were significant by Wilcoxon signed rank test statistically. The results show that dose coverage of target and OAR's doses also depend significantly on the collimator angles due to the geometry of target and OARs. Based on the results we have decided to plan prostate cancer patients in our clinic with double arc VMAT and 75°–285° collimator angles.

Key words: Collimator angle; double arc volumetric modulated arc therapy; patient quality assurances; prostate cancer

Introduction

Several studies have demonstrated the superiority of volumetric modulated arc therapy (VMAT) plans over the step-and-shoot intensity modulated (IMRT) approach in prostate cancer.[1,2] VMAT has less monitoring units (MUs), less treatment time, and more efficiency than static gantry angle IMRT.[3,4] The VMAT technology coordinates gantry rotation speed, multileaf collimator (MLC) motion, and dose rate modulation at the same time, because of these advantages, we can have highly conformal treatment and optimal sparing of the critical structures around target with single or multiple photon arcs in the treatment.[5]

MLC are the best tool for beam shaping and an important way to minimize the absorbed dose to organ at risk (OAR). They have moveable leaves arranged in pairs that can block

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a certain part of beam. Owing to its ability to control leaf position and with a large number of controlled leaves, it can be used to shape and desired fields.[6] The linear accelerator mechanical axes that are possible but not addressed in the current VMAT optimization approaches are the collimator angle and couch angle. However, collimator angle can rotate in the plans of VMAT to gain a better dose distribution. In other words, optimal choice of collimator angle can increase the optimization "freedom" to shape a desired dose distribution. This study is aimed to investigate the efficacy of dose distribution in eleven prostate cancer patients with single arc VMAT and double arc VMAT when varying collimator angle.

Materials and Methods

Patient selection and planning criteria

Eleven patients undergoing definitive VMAT for prostate cancer were included in this study. Clinical stage was as follows: T1c, T2a, T2b, and T2c. Clinical target volume (CTV) included the entire prostate plus 5 mm margin and depending on the patient's risk category with or without seminal vesicles plus 5 mm margin. Planning target volume (PTV) included CTV plus 5 mm margin (except at the CTV-rectum interface, where a 3 mm margin was used). The prescribed dose was 7600 cGy in 38 fractions to D95 (CTV), 7000 cGy in 38 fractions to D95 (CTV). The bladder volume receiving >6500 cGy should be <25%, and receiving >4000 cGy should be <50%. The rectum volume receiving >6500 cGy should be <17%, and receiving >4000 cGy should be <35%. The femur head volume receiving >4500 cGy should be <10% in our clinic's dose-volume criteria for OARs.[7-9]

Volumetric modulated arc therapy plan and treatment delivery

Patients were treated with 10 MV beam from a Versa HD® (Elekta, Crawley, England) linear accelerator equipped with Agility® collimator system, and XVI 4.5 cone beam computed tomography (CBCT) image guided radiation therapy.

The 160 leaves of Agility® are 5 mm in width at isocenter and are capable of interdigitation to enable treatment of island fields and multiple targets in a single session. The exceptionally low leaf transmission of <0.5% enhanced treatment delivery while reducing integral dose. Maximum MLC effective speed was 6.5 cm/s and maximum leaf travel was 15 cm over the central axis. The integrated whole results in a sophisticated, multi-functional beam-shaping solution. Maximum variable dose rate for each VMAT plans was 600 MUs/min. VMAT plans were generated on Monaco 5.0® (Elekta, Crawley, England) treatment planning system with Monte Carlo algorithm. The calculation parameters used were: grid spacing 0.3 cm, minimum segment width 0.5 cm, maximum 180 of control points per arc, fluence smoothing medium, statistical uncertainty 1% per plan, increment of gantry 30°, and dose to medium.

We generated optimum single and double arc VMAT treatment plans with collimator angle set to 0°. All plans were normalized 7600 cGy dose to the 95% of CTV volume. Then for eleven patients, we reoptimized single arc VMAT plans with different collimator angles (0°, 15°, 30°, 45°, 60°, 75°, and 90°), for double arc VMAT plans (0–0°, 15–345°, 30–330°, 45–315°, 60–300°, 75–285°, and 90–270°) using the same optimization parameters. Gantry was rotated from 180° to 179.9° in the clockwise direction for single arc VMAT. For double arc, VMAT also gantry was rotated from 180° to 179.9° in the clockwise direction, then gantry was rotated from 179.9° to 180° in the counter clockwise direction.

Dose-volume histogram evaluation

For dosimetric comparisons of VMAT plans in different collimator angles, we investigated dose-volume histograms (DVHs) of all treatment plans. We compared D95 (PTV), heterogeneity index (HI), V4000 cGy and V6500 cGy of rectum doses, V4000 cGy, and V6500 cGy of bladder doses, except femur head doses due to inconsiderable dose difference.

$$\text{Heterogeneity Index} = \frac{\text{D5 (minimum dose in 5\% of the target, indicating the "maximum dose")}}{\text{D95 (minimum dose in 95\% of the target, indicating the "minimum dose")}} \quad (1)$$

Dosimetric evaluation

After DVH evaluation, we determined better dose distribution with one collimator angle for single arc VMAT and one collimator angle for double arc VMAT. Then we compared both plans and we determined just one treatment method with one collimator angle. We performed patient specific quality assurances (QA) for eleven patient's VMAT plan with that collimator angle. The measurement were made by 2 dimensional ion chamber array IBA Matrixx® and three-dimensional IBA Compass® program. The Matrixx® has got 1020 pixel ion chambers arranged in 24.4 $cm^2 \times 24.4\ cm^2$. The distance between ion chambers were 7.6 mm. We used gantry holder which had 76 cm distance from source to ion chamber's surface and we used gantry sensor with Compass® software program. Compass® has got treatment planning program with collapsed cone algorithm. We recalculated our plans with collapsed cone algorithm. Hence, we used Compass® as a secondary treatment planning system. Then, we measured doses by Matrixx® and we evaluated our measurement by using patient's CT scan. Therefore, the comparison between calculation

Table 1: Dosimetric comparisons of single and double arc volumetric modulated arc therapy plans while varying collimator angle (cGy)

Collimator angles	*0°–0°*	*0°*	*15°–345°*	*15°*	*30°–330°*	*30°*	*45°–315°*	*45°*	*60°–300°*	*60°*	*75°–285°*	*75°*	*90°–270°*	*90°*
Patient 1	6900.3	7031.5	6919.3	7143.3	6943.6	7123.4	6994.8	7187.9	7060.3	7126.5	6998.1	7127.4	7050.7	7117.6
Patient 2	7234.4	7094.0	7178.1	7143.2	7277.4	6943.2	7284.3	7166.2	7288.0	6995.9	7298.3	7103.9	7259.5	7108.7
Patient 3	7260.3	6687.3	7246.1	6665.9	7276.6	6839.3	7244.0	6729.7	7276.1	6662.4	7290.6	6661.8	7220.0	6535.0
Patient 4	6855.8	6810.2	6851.9	6908.4	6847.5	6913.9	6904.2	6944.3	6935.7	6967.8	6913.6	6871.6	6821.1	6934.8
Patient 5	7212.6	7091.4	7203.7	7165.9	7206.7	7089.3	7221.5	7019.0	7240.6	7052.5	7294.4	7066.4	7244.4	7106.4
Patient 6	7208.0	7023.5	7279.7	6973.3	7273.9	7016.1	7320.6	6995.1	7311.3	7008.0	7328.7	7031.9	7289.7	6981.7
Patient 7	7056.4	6873.1	7077.0	6888.3	7141.4	6965.4	7108.8	6801.8	7125.6	6930.3	7039.6	6897.4	7099.0	6805.7
Patient 8	6994.4	6855.6	7070.6	6881.7	6900.4	6841.5	7061.1	6852.3	7148.9	6758.1	7116.5	6707.1	7187.6	6946.9
Patient 9	6764.4	6586.1	6798.7	6657.7	6757.4	6628.5	6884.8	6664.8	6790.3	6629.5	6841.5	6706.9	6822.9	6669.9
Patient10	6579.7	6585.5	6654.1	6609.3	6517.7	6602.3	6731.0	6540.5	6648.2	6553.6	6729.0	6506.7	6521.3	6485.5
Patient11	7119.1	6948.2	7098.2	7076.2	7162.5	7046.1	7154.6	7095.2	7177.4	7055.7	7169.7	7022.3	7146.0	7095.4
Mean±SD	7016.9±211	6871.5± 189	7034.3± 193	6919.4±205	7027.7±241	6909.9±172	7082.7±179	6908.8±210	7091.1±206	6885.5±198	7092.7±196	6882.1±209	7060.2±230	6889.8±234

SD: Standard deviation

and measurement were made by the γ-index (3%/3 mm) analysis for plans and each organs.

Statistical analysis

Wilcoxon signed rank test was used for multiple comparison of target and critical organs in different collimator angles. A $P \leq 0.05$ was defined as statistically significant.

Results

Treatment plan comparison

A higher D95 (PTV) were found for single VMAT in the 15° collimator angle, for double arc VMAT in the 60–300° and 75–285° collimator angles. These results are shown in Table 1. When we compared rectum doses for these collimator angles, we obtained lower rectum doses with 75–285° collimator angles [Table 2]. There was no significant dose difference for other OARs, which are bladder and femur head. When we compared single and double arc VMAT's dose distribution, we had better D95 (PTV) and lower HI with double arc VMAT. The mean HI index of CTV was 1.03 ± 0.005 and PTV was 1.10 ± 0.036 for double arc VMAT, the mean HI of CTV was 1.04 ± 0.012 and PTV was 1.14 ± 0.044 for single arc VMAT [Tables 3 and 4]. An average D95 (PTV) was 7092.7 cGy for double arc VMAT plan with 75–285° collimator angles, 6919.4 cGy for single arc VMAT plan with 15° collimator angle.

Dose verification of volumetric modulated arc therapy plan

First, we recalculated our plans with collapsed cone algorithm. Then we measured patient specific QAs when collimator angle was 75–285° in double arc VMAT plans by Matrixx® device and 3D Compass® software [Figure 1]. Table 5 gives the γ-index (3%/3 mm) evaluation results for

Table 2: Rectum volume doses for double arc volumetric modulated arc therapy

Collimator angles	*Rectum volume receiving >6500 cGy*		*Rectum volume receiving >4000 cGy*	
	60°–300° (%)	*75°–285° (%)*	*60°–300° (%)*	*75°–285° (%)*
Patient 1	13.44	13.27	26.48	26.27
Patient 2	2.54	2.54	11.59	11.82
Patient 3	7.34	7.80	25.85	26.11
Patient 4	4.58	4.81	17.64	18.04
Patient 5	11.75	11.38	31.55	31.54
Patient 6	3.05	2.92	14.07	13.41
Patient 7	7.94	7.91	20.99	21.06
Patient 8	5.61	5.36	16.25	16.07
Patient 9	12.78	12.30	26.38	26.10
Patient 10	2.52	2.41	9.94	9.78
Patient 11	7.45	6.64	20.21	19.94
Mean (%)±SD	7.18±0.04	7.03±0.04	20.86±0.07	20.01±0.07

SD: Standard deviation

Table 3: A comparison between single and double arc volumetric modulated arc therapy plan's heterogeneity index of clinical target volume

Collimator angle	*Double VMAT 75°–285°*	*Single VMAT 15°*
Patient 1	1.04	1.04
Patient 2	1.04	1.05
Patient 3	1.04	1.07
Patient 4	1.04	1.06
Patient 5	1.03	1.03
Patient 6	1.03	1.04
Patient 7	1.03	1.04
Patient 8	1.03	1.04
Patient 9	1.03	1.04
Patient 10	1.03	1.04
Patient 11	1.03	1.03
Mean±SD	1.03±0.005	1.04±0.012

VMAT: Volumetric modulated arc therapy, SD: Standard deviation

Table 4: A comparison between single and double arc volumetric modulated arc therapy plan's heterogeneity index of planning target volume

Collimator angle	*Double VMAT 75°–285°*	*Single VMAT 15°*
Patient 1	1.07	1.10
Patient 2	1.07	1.10
Patient 3	1.12	1.18
Patient 4	1.11	1.15
Patient 5	1.15	1.21
Patient 6	1.09	1.10
Patient 7	1.12	1.14
Patient 8	1.07	1.10
Patient 9	1.17	1.21
Patient 10	1.06	1.11
Patient 11	1.11	1.12
Mean±SD	1.10±0.036	1.14±0.044

VMAT: Volumetric modulated arc therapy, SD: Standard deviation

Table 5: An average γ-index evaluation between calculation and measurement for targets and organ at risks

	An average γ-index					
	CTV	*PTV*	*Bladder*	*Rectum*	*Right femur head*	*Left femur head*
Patient 1	0.35	0.28	0.18	0.25	0.16	0.17
Patient 2	0.47	0.39	0.34	0.31	0.27	0.20
Patient 3	0.22	0.25	0.16	0.30	0.16	0.16
Patient 4	0.37	0.33	0.32	0.21	0.22	0.17
Patient 5	0.28	0.26	0.18	0.35	0.24	0.21
Patient 6	0.34	0.31	0.21	0.29	0.28	0.21
Patient 7	0.28	0.27	0.22	0.30	0.20	0.17
Patient 8	0.48	0.37	0.33	0.36	0.16	0.19
Patient 9	0.25	0.23	0.31	0.18	0.16	0.14
Patient 10	0.48	0.39	0.30	0.27	0.26	0.21
Patient 11	0.47	0.40	0.28	0.36	0.15	0.16
Mean±SD	0.36± 0.09	0.32± 0.06	0.26± 0.06	0.29± 0.06	0.21± 0.05	0.18± 0.02

PTV: Planning target volume, CTV: Clinical target volume, SD: Standard deviation

Table 6: Dosimetric evaluation between calculation and measurement for D95 (planning target volume) when collimator angle were 75°–285° cGy

	Compass calculation with Collapse Cone algorithm	*Measurement by matrixx*	*Dose difference (%)*
Patient 1	6598.3	6588.8	0.1
Patient 2	6974.9	6906.1	1.0
Patient 3	6737.9	6781.4	0.6
Patient 4	6876.4	6792.1	1.2
Patient 5	6803.0	6757.8	0.7
Patient 6	6994.4	6941.9	0.8
Patient 7	6882.4	6915.1	0.3
Patient 8	7138.5	7173.5	0.5
Patient 9	7171.9	7173.1	0.0
Patient 10	7178.1	7194.9	0.2
Patient 11	6980.4	6868.1	1.6
Mean (%)±SD	6939.7±176	6917.5±186	0.6±0.005

SD: Standard deviation

Table 7: A comparison of collimator angles statistically for D95 (planning target volume) with double arc volumetric modulated arc therapy

Collimator angles (°)	*Collimator angles (°)*	*P*
0–0	15–345	0.248
0–0	30–330	0.477
0–0	45–315	0.006
0–0	60–300	0.003
0–0	75–285	0.004
0–0	90–270	0.131

Table 8: A comparison of collimator angles statistically for D95 (planning target volume) with single arc volumetric modulated arc therapy

Collimator angles (°)	*Collimator angles (°)*	*P*
0	15	0.026
0	30	0.131
0	45	0.213
0	60	0.594
0	75	0.656
0	90	0.534

targets and OARs by 3D Compass® software. Dosimetric evaluation between calculation and measurement for D95 (PTV) are shown in Table 6. We found more than 97% passing rate for all plans in γ-index (3%/3 mm) analysis. These results showed us, we had high precise dose delivery in the linear accelerator with these collimator angles as we had planned in the treatment planning system. Therefore, we could suggest these collimator angles.

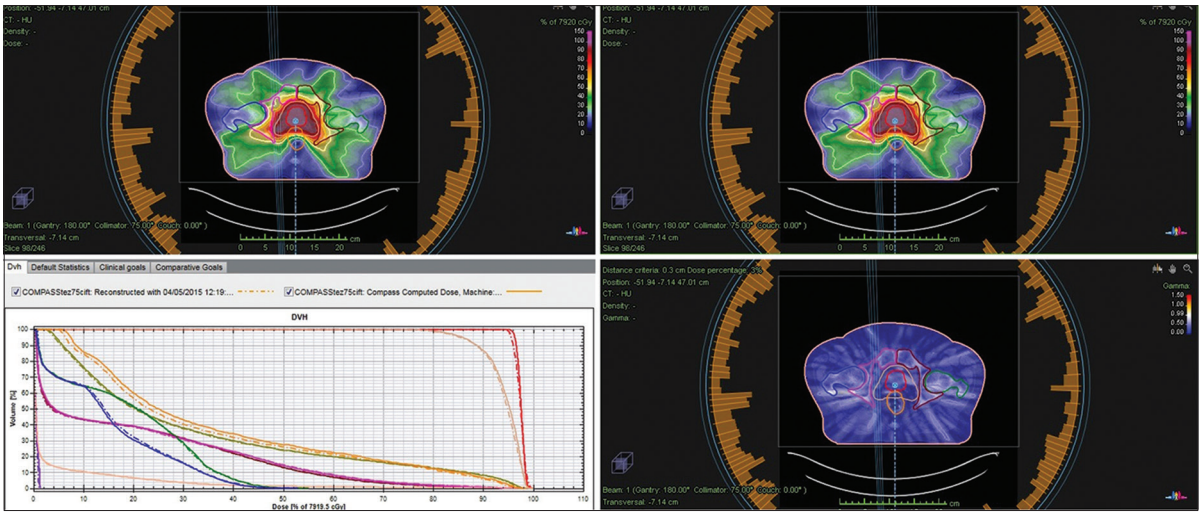

Figure 1: Dosimetric evaluation between calculation and measurement for one patient's double arc volumetric modulated arc therapy plan when collimator angles were 75–285°

Statistical analysis result

When we compared D95 (PTV) results at collimator 0° with other collimator angles for single arc VMAT by Wilcoxon Rank test statistically, we determined $P = 0.026$ for 15° collimator angle [Table 7]. For double arc VMAT, we determined $P = 0.004$ for 75–285° collimator angles [Table 8].

Discussion

An investigation of the dose distribution related with collimator angles reveals that while a 15° collimator angle plan has on an average 0.7% higher D95 (PTV) than the 0° collimator angle plan in the case of single arc VMAT technique, a 75–285° collimator angle plan has on an average 1.07% higher dose coverage than the collimator 0° plan in the case of double arc VMAT technique. Several randomized trials have shown that higher radiation doses result in 15–20% increase in biochemical control of localized prostate cancer.[10,11] The results show that dose coverage of target and OAR's doses also depend significantly on the collimator angles due to the geometry of target and OARs.

When we compared single and double arc VMAT D95 (PTV), we found on an average 2.44% high coverage with double arc VMAT. In addition, the mean HI index of CTV and PTV were better with double arc VMAT than single arc VMAT. When we measured patient specific QAs, we found on an average 0.6% dose difference between calculation and measurement and the average γ-index for CTV 0.36, for PTV 0.32 with double arc VMAT. It showed us, we had high precise dose delivery in the linear accelerator and we can be sure about the calculation accuracy for our plans and the different gantry angles tried did not affect the dose distribution due to gravity effect on MLC.

Conclusion

Our method, which relies on the geometry of prostate and OARs to determine the optimal collimator angle before VMAT optimization. These finds are informative, first for choosing double arc VMAT plan instead of single arc VMAT plan, second for choosing 75–285° collimator angles for double arc VMAT plan. These results were significant by Wilcoxon signed rank test statistically also. Based on the results, we have decided to plan prostate cancer patients in our clinic with double arc VMAT and 75–285° collimator angles.

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Conflicts of interest

There are no conflicts of interest.

References

1. Kjaer-Kristoffersen F, Ohlhues L, Medin J, Korreman S. RapidArc volumetric modulated therapy planning for prostate cancer patients. Acta Oncol 2009;48:227-32.
2. 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.
3. Lee FK, Yip CW, Cheung FC, Leung AK, Chau RM, Ngan RK. Dosimetric difference amongst 3 techniques: TOMOTHERAPY, sliding-window intensity-modulated radiotherapy (IMRT), and Rapid Arc radiotherapy in the treatment of late-stage nasopharyngeal carcinoma (NPC). Med Dosim 2014;39:44.
4. Lee TF, Chao PJ, Ting HM, Lo SH, Wang YW, Tuan CC, *et al.* Comparative analysis of SmartArc-based dual arc volumetric-modulated arc radiotherapy (VMAT) versus intensity-modulated radiotherapy (IMRT) for nasopharyngeal carcinoma. J Appl Clin Med Phys 2011;12:3587.
5. Pardo-Montero J, Fenwick JD. An approach to multiobjective optimization of rotational therapy. Med Phys 2009;36:3292-303.

6. Boyer A, Biggs P, Galvin J, Klein E, Losasso T, Low D, *et al*. Basic applications of multileaf collimators: Report of the AAPM radiation therapy committee Task Group 50. Med Phys 2001;72:16-40.
7. Marks LB, Yorke ED, Jackson A, Ten Haken RK, Constine LS, Eisbruch A, *et al*. Use of normal tissue complication probability models in the clinic. Int J Radit Oncol Biol Phys 2010;76:10-9.
8. Michalski JM, Gay H, Jackson A, Tucker SL, Deasy JO. Radiation dose volume effects in radiation induced rectal injury. Int J Radit Oncol Biol Phys 2010;76 3 Suppl: 123-9.
9. Viswanathan AN, Yorke ED, Marks LB, Eifel PJ, Shipley WU. Radiation dose volume effects of the urinary bladder. Int J Radit Oncol Biol Phys 2010;76:116-22.
10. Dearnaley DP, Sydes MR, Graham JD, Aird EG, Bottomley D, Cowan RA, *et al*. Escalated-dose versus standard-dose conformal radiotherapy in prostate cancer: First results from the MRC RT01 randomised controlled trial. Lancet Oncol 2007;8:475-87.
11. Pollack A, Zagars GK, Starkschall G, Antolak JA, Lee JJ, Huang E, *et al*. Prostate cancer radiation dose response: Results of the M. D. Anderson phase III randomized trial. Int J Radiat Oncol Biol Phys 2002;53:1097-105.