Reports of Practical Oncology and Radiotherapy 25 (2020) 974–980

Available online at www.sciencedirect.com

Reports of Practical Oncology and Radiotherapy

journal homepage: http://www.elsevier.com/locate/rpor

Original research article

The effect of rectal gas on dose distribution during prostate cancer treatment using full arc and partial arc Volumetric Modulated Arc Therapy (VMAT) treatment plans

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ARTICLE INFO

Article history:
Received 25 May 2020
Received in revised form 10 August 2020
Accepted 21 September 2020
Available online 11 October 2020

Keywords:
Volumetric modulated arc therapy
Gas
Dose distribution
Prostate cancer

ABSTRACT

Background/Aim: In this study, we investigated the effect of rectal gas on the dose distribution of prostate cancer using a volumetric modulated arc therapy (VMAT) treatment planning.
Materials and Methods: The first is the original structure set, clinical target volume (CTV), the rectum, and the bladder used clinically. The second is a structure set (simulated gas structure set) in which the overlapping part of the rectum and PTV is overwritten with Hounsfield Unit −950 as gas. Full arc and limited gantry rotation angle with VMAT were the two arcs. The VMAT of the full arc was 181°–179° in the clockwise (CW) direction and 179°–181° in the counterclockwise (CCW) direction. Three partial arcs with a limited gantry rotation angle were created: 200°–160 °CW and 160°–200 °CCW; 220°–140 °CW and 140°–220 °CCW; and finally, 240°–120 °CW and 120°–240 °CCW. The evaluation items were dose difference, distance to agreement, and gamma analysis.
Result: In the CTV, the full arc was the treatment planning technique with the least effect of rectal gas. In the rectum, when the gantry rotation angle range was short, the pass rate tended to reduce for all evaluation indices. The bladder showed no characteristic change between the treatment planning techniques in any of the evaluation indices.
Conclusions: The VMAT treatment planning with the least effect on dose distribution caused by rectal gas was shown to be a full arc.

1. Background

Radiotherapy has undergone a series of advancements in recent decades, from the technique of intensity modulated radiation therapy (IMRT) to the development of volumetric modulated arc therapy (VMAT). VMAT is a therapeutic technique that allows a simultaneous modulation of a number of photons emitted by altering the treatment aperture shape of the multi-leaf collimator (MLC), the dose rate, and the speed of the gantry.[1] There are many reports that VMAT has a shorter treatment time than IMRT and can achieve a similar dose distribution.[2–4] Consequently, in the field of radiation therapy, VMAT has become more popular than IMRT due to the increase in the number of cases and the expansion of indications for the treatment site. Especially for prostate cancer, VMAT is performed at many institutions to reduce treatment time.

IMRT in prostate cancer has been reported to render good outcomes with a mild incidence of acute and late toxicity.[5] Radiation therapy for prostate cancer requires high doses of about 80 Gy for local control.[6] Therefore, for prostate cancer VMAT, the National Comprehensive Cancer Network guidelines[6] recommend image-guided radiation therapy (IGRT). IGRT improves the precision of the treatment delivery through the comparison of pre-treatment and treatment planning images to confirm the irradiation position matching.

There are two main types of IGRT position matching. One is based on bone matching using two-dimensional images such as kV-imaging or an electric portal imaging device. The other is based on the target position using three-dimensional images such as cone-beam computed tomography (CBCT). The prostate is a target that is displaced and deformed independently of the bone structure and

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https://doi.org/10.1016/j.rpor.2020.09.013
1507-1367/

moves due to the effects of the bladder and rectum filling. Therefore, the filling condition of the bladder and rectum during each radiation treatment must be as close as possible to the state of the CT taken for radiation treatment planning. Preprocessing for radiation therapy for prostate cancer includes urine from the bladder and rectal contents such as feces and gas. If preprocessing is not possible, it is difficult to deliver the prostate treatment daily in response to prostate displacement and deformation due to bone alignment. In this situation, target matching by CBCT is recommended.[7] Previous reports have shown that rectal gas has the most significant effect on prostate displacement and deformation compared to others.[8,9] Moreover, there has been a report investigating the effect of rectal gas, which is not present at the time of treatment planning for prostate IMRT and VMAT, on the dose distribution when rectal gas is present during actual treatment.[2] This report[2] assumes that there is no displacement or change in the position of the prostate, suggesting that the presence or absence of rectal gas has less effect on the dose distribution during IMRT than VMAT. However, VMAT in this report[2] is a treatment plan in a full arc. Hence, the same result is not always obtained when a part of the gantry rotation angle is limited.

2. Aim

The purpose of this study was to investigate the impact of rectal gas on dose distribution in VMAT treatment plans in which the full arc and gantry rotation angles were partially restricted.

3. Materials and methods

This study involved fifteen patients who underwent prostate VMAT at our institution. An anisotropic analytical algorithm (AAA) in the Eclipse (Varian Medical Systems, Palo Alto, CA., USA) treatment planning system (TPS, version 11.0.31) was used to calculate the dose. The Optima CT 580 W (General Electric Medical Systems, Waukesha, WI., USA) CT system was used for imaging, with a slice thickness of 2.5 mm. The TrueBeam (Varian Medical Systems, Palo Alto, CA, USA) linear accelerator used an energy setting of 10×. Clinical target volume (CTV) and rectum and bladder delineation settings were performed according to the method of Sasaki et al.[2] The planning target volume (PTV) was set at 6 mm only behind the CTV and 8 mm in the other directions. In this study, it was assumed that there was no displacement or deformation of the prostate when evaluating the effect of rectal gas on the dose distribution. To evaluate differences in rectal gas dose distributions, a Hounsfield Unit (HU) −950 was simulated for the overlapping part (overlap) of the rectum and PTV. This retrospective study was approved by the Institutional Review Board of our institution (Approval No. 3434).

3.1. Treatment planning

Full arc and limited gantry rotation angle with VMAT were the two arcs. The VMAT of the full arc was 181°–179° in the clockwise (CW) direction and 179°–181° in the counterclockwise (CCW) direction. Three partial arcs with a limited gantry rotation angle were created: 200°–160 °CW and 160°–200 °CCW; 220°–140 °CW and 140°–220 °CCW; and finally, 240°–120 °CW and 120°–240 °CCW. These three partials arcs will be referred to as 200°–160°, 220°–140°, 240°–120°, respectively, in the rest of this paper. The collimator rotation angles of 30° and 330° were adopted in both VMAT plans. The prescription dose in this study was 78 Gy/39 fractions and was a dose (D95%) that included 95% of the volume of the PTV excluding rectum obtained by subtracting the rectum overlap from the PTV.

Table 1
Dose-volume constraints used in treatment planning.

Structurer	Dose constraint
PTV excluding rectum	D95% = 100%
	Maxdose < 110%
CTV	V100%(%) ≥ 99.5%
Rectum	V40 Gy(%) ≤ 50%
	V60 Gy(%) ≤ 25%
	V70 Gy(%) ≤ 15%
	V75 Gy(%) ≤ 5%
Bladder	V40 Gy(%) ≤ 50%
	V65 Gy(%) ≤ 25%

In this study, dose calculations were performed using two types of structure sets. The first is the original structure set, CTV, PTV excluding rectum, the rectum, and the bladder used clinically. The second is a structure set (simulated gas structure set) in which the overlap is overwritten with HU as gas, as described above. The rectal gas volume relative to the rectum contour volume used in the treatment plan was less than 5% in all the cases. In all the cases, the four treatment plans described above were created for the original structure set. Then, in order to evaluate the effect of rectal gas on the dose distribution, re-calculation was performed using the simulated gas structure set with the same iso-center as the original structure set. During the re-calculation, the optimization work was not performed again, and the gantry speed, MLC shape, and dose rate did not change.

3.2. Evaluation of original VMAT treatment plan

If the difference between the four plans could be minimized, it will be possible to quantify/study the effect of rectal gas on dose distribution. Therefore, significance tests of the four treatment plans created using the original structure set were performed using a paired *t*-test of parametric statistics. The significance level was set at $p < 0.05$. The evaluation items were selected based on the dose constraints of our institution shown in Table 1.

3.3. Effect of dose distribution with and without rectal gas

Next, using the simulated gas structure set, the difference between the recalculated dose distribution and the original VMAT treatment plan was evaluated. The purpose of this study was to examine the variation of the dose distribution among the four original treatment plans depending on the presence or absence of rectal gas. Therefore, we carried out the recalculations and no re-optimization was performed. The PTV excluding rectum, the CTV, the rectum, and the bladder were evaluated using the 3DVH version 2.2.1 (Sun Nuclear Corporation, Melbourne, FL, USA), a three-dimensional (3D) dose verification software. The evaluation items were dose difference (DD), distance to agreement (DTA), and gamma analysis (GA). DD was evaluated at 1%, 2%, and 3%; DTA at 1 mm, 2 mm, and 3 mm; and GA at 1 mm/1%, 2 mm/2%, and 3 mm/3%. In this study, 3DVH was used to objectively assess the differences in the dose distribution with and without simulated rectal gas in the same treatment plan. To evaluate the effect of dose distribution with and without rectal gas on each treatment plan, a significance test was performed using a paired *t*-test of parametric statistics. The significance level was set at $p < 0.05$.

4. Result

4.1. Original VMAT treatment plan

Table 2 shows the results of the treatment planning for four original VMATs based on the dose constraints shown in Table 1.

Table 2
Dosimetric comparison of organs at risk and target dose of full arc and limited gantry rotation angle with volumetric modulated arc therapy plans.

Structurer	Dose constraint	Technique			
		Full arc	200°–160°	220°–140°	240°–120°
CTV	V100%(%)	99.97 ± 0.04	99.97 ± 0.04	99.98 ± 0.03	99.94 ± 0.16
Rectum	V40 Gy(%)	30.60 ± 3.21	30.64 ± 3.47	30.76 ± 3.65	31.23 ± 4.01
	V60 Gy(%)	15.24 ± 1.96	15.43 ± 2.11	15.74 ± 2.18	16.13 ± 2.36
	V70 Gy(%)	7.68 ± 1.29	8.15 ± 1.45	8.48 ± 1.50	8.74 ± 1.65
	V75 Gy(%)	3.03 ± 1.14	3.71 ± 1.42	4.02 ± 1.44	4.22 ± 1.55
Bladder	V40 Gy(%)	31.59 ± 6.61	31.95 ± 7.23	31.84 ± 7.43	32.76 ± 8.77
	V65 Gy(%)	11.83 ± 4.29	11.78 ± 4.35	11.97 ± 4.36	12.37 ± 4.47

Structurer	Dose constraint	*p*-value					
		Full arc vs 200°–160°	Full arc vs 220°–140°	Full arc vs 240°–120°	200°–160° vs 220°–140°	200°–160° vs 240°–120°	220°–140° vs 240°–120°
CTV	V100%(%)	0.772	0.670	0.463	0.478	0.528	0.389
Rectum	V40 Gy(%)	0.947	0.947	0.682	0.924	0.670	0.742
	V60 Gy(%)	0.806	0.521	0.272	0.697	0.397	0.637
	V70 Gy(%)	0.359	0.127	0.060	0.538	0.306	0.661
	V75 Gy(%)	0.160	**0.045**	**0.024**	0.547	0.351	0.722
Bladder	V40 Gy(%)	0.889	0.922	0.683	0.969	0.784	0.760
	V65 Gy(%)	0.972	0.933	0.740	0.906	0.716	0.805

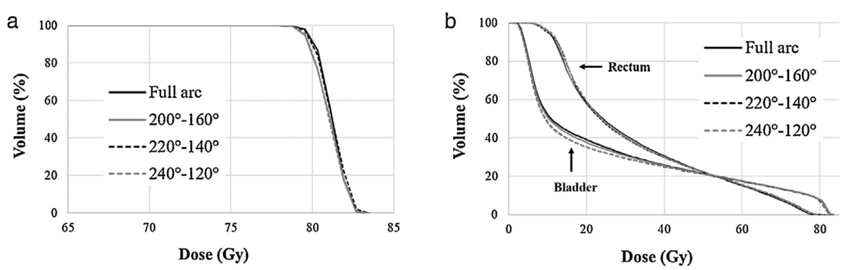

Fig. 1. The average dose-volume histogram of (a) clinical target volume (CTV) and (b) rectum in the four volumetric modulated arc therapy treatment plans.

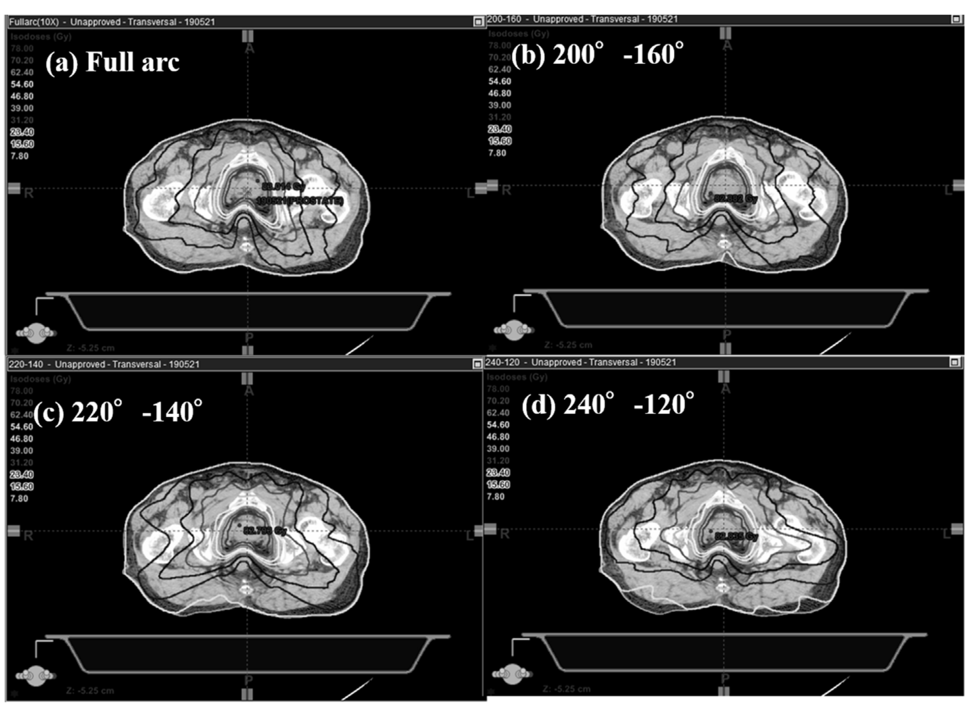

Fig. 2. The average dose distribution the full arc and limited gantry rotation angle with VMAT plans. (a) Full arc, (b) 200°–160°, (c) 220°–140°, (d) 240°–120°.

Fig. 1 shows the average dose-volume histogram (DVH) of CTV and organ at risk (OAR) in the four original VMAT treatment plans in this study, and Fig. 2 shows the dose distribution. CTV V100% did not show any characteristic change in the difference between the VMAT plans. At the dose constraint in the rectum, the shorter the gantry rotation angle range, the lower the dose that can be reduced in the rectum. Moreover, the shorter the gantry rotation angle range, the greater the variation among cases. There was a significant difference between the treatment plans for rectum V75 Gy [full arc and 220°–140° (p = 0.045) and full arc and 240°–120° (p = 0.024)]. At the bladder in V40 Gy, the shorter the gantry rotation angle range, the smaller the dose that can be reduced by the bladder, and the larger the variation, as was the point of the dose constraint of the rectum. Bladder V65 Gy did not show any characteristic changes in the differences in the VMAT plan.

4.2. Effect of dose distribution with and without rectal gas

Table 3 shows the difference in relative doses at the point of dose constraint depending on the presence or absence of rectal gas. The reference dose distribution is the original structure set without simulated gas in the rectum. Fig. 3 shows the CTV and rectum DVH with and without rectal gas in the four VMAT treatment planning techniques in this study. In PTV excluding rectum D95% and CTV V100%, the dose of the simulated gas structure set tended to be smaller than that of the original structure set, resulting in a dose reduction of about 0.28–0.68%. However, no characteristic change was observed between the treatment planning techniques.

For the rectum, the dose tended to be higher in the simulated gas structure set than in the original structure set at V40 Gy and V60 Gy. Contrarily, in V70 Gy and V75 Gy, the dose tended to be lower in the simulated gas structure set than in the original structure set. The dose relationship between the original structure set and the simulated gas structure set was reversed at a dose of around 60 Gy from the DVH shown in Fig. 3. Additionally, in the case of rectums V40 Gy and V70 Gy, the shorter the gantry rotation angle range, the more significant the dose difference compared to the original structure set. However, no characteristic changes were observed in V60 Gy and V75 Gy. Furthermore, there was no characteristic change in the variability between cases with or without rectal gas in the four VMAT treatment planning techniques.

Regarding the bladder, no characteristic changes were observed in the treatment planning techniques for the four VMATs with or without rectal gas, and no variation was observed between the cases.

Table 4 shows the results of DD, DTA, and GA, which are indicators of the degree of coincidence of the dose distribution with and without rectal gas for each treatment plan. In the PTV excluding rectum and CTV, the full arc was the most suitable treatment planning technique for DD, DTA, and GA pass rate result. In CTV, there were significant differences between the full arc and the 220°–140° treatment planning techniques for DTA 1 mm (p = 0.042), 2 mm (p = 0.030), and 3 mm (p = 0.035). In CTV, there was a significant difference in DTA 2 mm (p = 0.043) between the full arc and the 240°–120° treatment planning technique. No characteristics changes were observed in CTV and PTV excluding rectum, among other treatment planning techniques.

When looking at the impact on the rectum, there was no significant difference when using the original structure set. However, when the gantry rotation angle range was short, the pass rate tended to reduce for all evaluation indices. There was a significant difference in GA 1 mm/1% (p = 0.032) between the full arc and 240°–120° treatment planning techniques. No characteristic changes were observed between the other treatment planning techniques.

The bladder showed no characteristic change between the treatment planning techniques in any of the evaluation indices. No significant difference was observed in any of the evaluation indices.

5. Discussion

Based on the results shown in Table 2, Fig. 1 (a), and Fig. 2, there was no significant difference between the treatment planning techniques concerning the target coverage, and it is considered that the treatment planning quality was practically the same. In contrast, rectum V75 Gy showed significant differences between the full arc and the 220°–140°, and the full arc and the 240°–120° treatment plans. However, the DVH shape of the rectum shown in Fig. 1 (b) shows a similar shape among the four treatment planning techniques. From the dose distribution between the treatment planning techniques shown in Fig. 2, the dose intervals in the anterior-posterior direction to the rectum are almost the same from a high dose to low dose. Therefore, for the rectum, it is considered that the treatment plan quality was virtually the same among the four treatment planning techniques. For the bladder, as shown in Table 2, the p-values between treatment planning techniques are large, and there is no characteristic difference. Therefore, it is considered that there is no significant difference in the dose distribution for CTV and OAR among the four treatment planning techniques, and it can be considered that the dose distribution is similar.

Prior reports have detailed their findings regarding the effects of rectal gas on the dose distribution of prostate IMRT and VMAT.[2] This study takes this work further by investigating the effect of rectal gas on dose distribution by overwriting the HU value at −950 in the region where the PTV and rectum overlap, assuming that there is no positional displacement and deformation of CTV and OAR. The X-ray energy used in this study was 10×, but the past report was 15×. Similar to the treatment planning technique in previous studies, this study uses a full arc, showing different values of the DD, DTA, and GA pass ratio results. However, the dose trends for the CTV and rectum using the original structure set and the simulated gas structure set were similar. Therefore, it is considered that the difference in the pass ratio is due to the difference in energy. The relationship between the pass ratio of DD and DTA is the same as in previous reports. Specifically, the pass ratio of DD was higher in the CTV than in DTA, but the pass ratio of DTA in the rectum was higher than that of DD. From these facts, it can be inferred that the effect of rectal gas is smaller at low energies. However, care must be taken because the results of the pass rate may differ depending on the case.

Ogino et al. in a previous study evaluated the relationship between the intra-fractional motion of the prostate in patients and

Table 3
Relative dose difference at the point of dose constraint with and without rectal gas.

Structurer	Dose constraint	Technique			
		Full arc	200°–160°	220°–140°	240°–120°
CTV	V100%(%)	−0.51 ± 0.56	−0.60 ± 0.66	−0.68 ± 0.74	−0.58 ± 0.83
Rectum	V40 Gy(%)	0.79 ± 1.06	0.92 ± 1.15	1.06 ± 1.15	1.23 ± 1.26
	V60 Gy(%)	0.55 ± 1.06	0.53 ± 1.09	0.60 ± 0.96	0.68 ± 0.93
	V70 Gy(%)	−4.10 ± 3.66	−4.22 ± 3.67	−4.40 ± 3.81	−4.91 ± 4.28
	V75 Gy(%)	−29.96 ± 19.24	−28.13 ± 20.08	−27.64 ± 18.07	−30.06 ± 20.57
Bladder	V40 Gy(%)	−0.02 ± 0.25	−0.04 ± 0.24	−0.05 ± 0.23	−0.06 ± 0.24
	V65 Gy(%)	−0.02 ± 0.70	−0.07 ± 0.07	−0.10 ± 0.70	−0.14 ± 0.64

Table 4
Results of dose difference (DD), distance to agreement (DTA), and gamma analysis (GA), which are indicators of the degree of coincidence of dose distribution depending on the presence or absence of rectal gasc.

Structurer	Dose constraint	Technique				*p*-value					
		Full arc	200°–160°	220°–140°	240°–120°	Full arc vs 200°–160°	Full arc vs 220°–140°	Full arc vs 240°–120°	200°–160° vs 220°–140°	200°–160° vs 240°–120°	220°–140° vs 240°–120°
CTV	DD1%(%)	93.50 ± 5.59	91.78 ± 6.41	90.85 ± 6.92	91.91 ± 6.63	0.440	0.258	0.484	0.704	0.956	0.670
	DD2%(%)	98.53 ± 2.35	97.79 ± 3.01	97.36 ± 3.33	98.02 ± 2.64	0.463	0.278	0.583	0.711	0.828	0.552
	DD3%(%)	99.71 ± 0.69	99.41 ± 1.21	99.23 ± 1.54	99.55 ± 0.93	0.414	0.276	0.598	0.715	0.726	0.489
	DTA1 mm(%)	75.64 ± 9.79	71.65 ± 12.57	66.93 ± 12.41	67.18 ± 12.96	0.341	**0.042**	0.054	0.310	0.346	0.958
	DTA2 mm(%)	91.55 ± 4.29	89.05 ± 5.77	86.92 ± 6.49	87.36 ± 6.30	0.189	**0.030**	**0.043**	0.351	0.451	0.852
	DTA3 mm(%)	96.80 ± 2.06	95.25 ± 3.26	94.18 ± 4.01	94.76 ± 3.22	0.134	**0.035**	0.051	0.429	0.680	0.666
	GA1 mm / 1%(%)	94.99 ± 4.60	92.84 ± 5.90	91.80 ± 6.54	92.74 ± 6.10	0.277	0.135	0.265	0.651	0.964	0.687
	GA2 mm / 2%(%)	99.52 ± 0.98	98.99 ± 1.84	98.73 ± 2.07	99.24 ± 1.31	0.338	0.198	0.512	0.719	0.675	0.431
	GA3 mm / 3%(%)	99.96 ± 0.17	99.81 ± 0.49	99.75 ± 0.61	99.95 ± 0.15	0.359	0.255	0.908	0.745	0.329	0.236
Rectum	DD1%(%)	86.46 ± 14.76	83.69 ± 15.78	80.21 ± 16.62	78.08 ± 17.49	0.623	0.285	0.167	0.561	0.365	0.735
	DD2%(%)	95.14 ± 9.85	93.63 ± 10.85	91.94 ± 11.38	90.89 ± 12.72	0.692	0.417	0.316	0.681	0.523	0.814
	DD3%(%)	97.18 ± 6.84	96.49 ± 7.62	95.81 ± 8.29	95.45 ± 9.08	0.797	0.626	0.562	0.817	0.737	0.911
	DTA1 mm(%)	99.68 ± 0.50	99.35 ± 1.01	99.07 ± 1.48	98.85 ± 1.61	0.273	0.151	0.073	0.550	0.313	0.692
	DTA2 mm(%)	99.98 ± 0.04	99.93 ± 0.12	99.89 ± 0.20	99.89 ± 0.22	0.165	0.118	0.152	0.508	0.539	-
	DTA3 mm(%)	99.99 ± 0.03	99.99 ± 0.04	99.99 ± 0.04	99.99 ± 0.03	0.559	0.559	-	-	0.559	0.559
	GA1 mm / 1%(%)	99.74 ± 0.52	99.39 ± 1.02	99.07 ± 1.48	98.72 ± 1.61	0.255	0.118	**0.032**	0.498	0.185	0.537
	GA2 mm / 2%(%)	99.99 ± 0.03	99.96 ± 0.11	99.93 ± 0.18	99.93 ± 0.15	0.253	0.184	0.108	0.547	0.485	-
	GA3 mm / 3%(%)	100.00 ± 0.00	100.00 ± 0.00	99.99 ± 0.03	100.00 ± 0.00	-	0.334	-	0.334	-	0.334
Bladder	DD1%(%)	99.75 ± 0.53	99.69 ± 0.56	99.62 ± 0.66	99.63 ± 0.67	0.792	0.566	0.590	0.745	0.770	0.978
	DD2%(%)	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	-	-	-	-	-	-
	DD3%(%)	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	-	-	-	-	-	-
	DTA1 mm(%)	99.65 ± 0.42	99.61 ± 0.51	99.57 ± 0.52	99.60 ± 0.48	0.787	0.618	0.748	0.833	0.971	0.856
	DTA2 mm(%)	99.85 ± 0.18	99.85 ± 0.22	99.85 ± 0.18	99.87 ± 0.18	0.928	-	0.763	0.928	0.721	0.763
	DTA3 mm(%)	99.91 ± 0.12	99.92 ± 0.10	99.92 ± 0.09	99.93 ± 0.13	0.874	0.870	0.669	-	0.756	0.749
	GA1 mm / 1%(%)	100.00 ± 0.00	99.99 ± 0.04	100.00 ± 0.00	100.00 ± 0.00	0.164	-	-	0.164	0.164	-
	GA2 mm / 2%(%)	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	-	-	-	-	-	-
	GA3 mm / 3%(%)	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	-	-	-	-	-	-

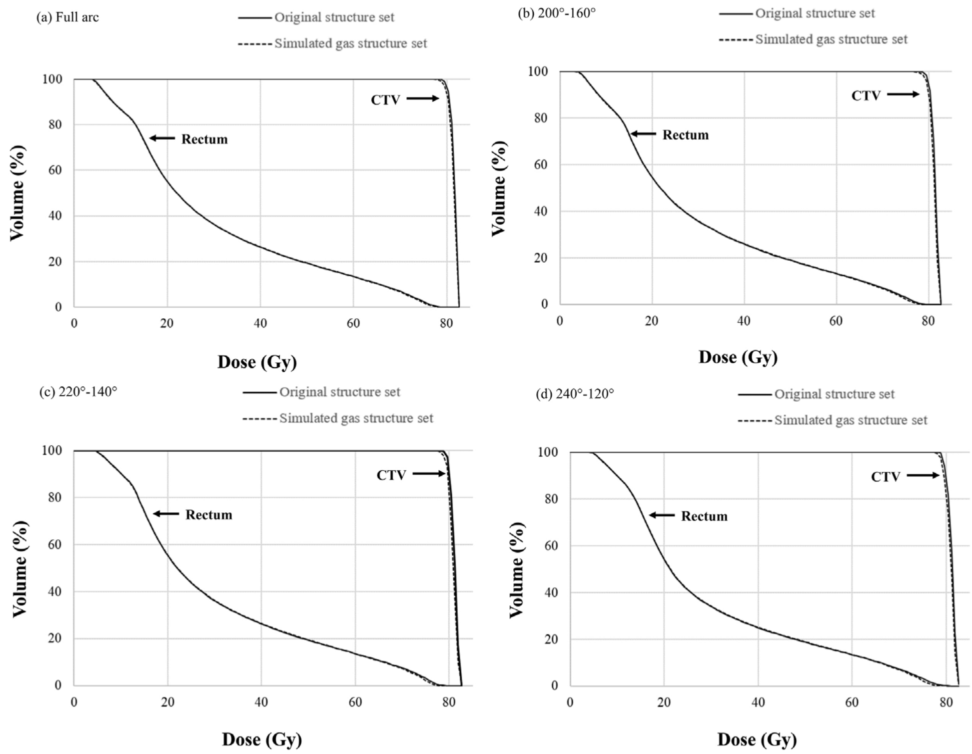

Fig. 3. Clinical target volume (CTV) and rectum dose-volume histogram with and without rectal gas in the Full arc and limited gantry rotation angle with volumetric modulated arc therapy plans (a) Full arc, (b) 200°–160°, (c) 220°–140°, (d) 240°–120°.

gas present in the rectal contents. They concluded that the presence of rectal gas was associated with prostate displacement and rectal movement in patients.[10] Another study performed IGRT to study the variability of delivery dose to the prostate, rectum, and bladder during a full course of external beam radiotherapy; the IGRT images acquired were CBCTs of MV beams from Tomotherapy, which showed large variation in delivery dose to the prostate, rectum, and bladder.[11]

Other reports indicated that patients with a bulging rectum at the time of treatment planning CT scans had worse biochemical progression-free survival than patients with an empty rectum.[12–14] Rectal volume is known to decrease during the treatment, especially in patients with large rectal volumes during planning CT. As a result, the prostate gland may move posteriorly from its predefined PTV and cancer may not be adequately treated. This confirms that IGRT based on bone landmarks is inadequate and that more sophisticated IGRT techniques are needed.

However, even when IGRT is performed, there may be no rectal gas present at the time of treatment planning CT scan, but gas may be present in the rectum on the CBCT taken immediately before the treatment. In some cases, this is experienced without deformity and displacement of the prostate. In the present study, we investigate the effect of the presence or absence of rectal gas on the dose distribution in the absence of prostate deformity and displacement.

The purpose of this study was to investigate a VMAT treatment plan in which rectal gas had little effect on dose distribution. DD, DTA, and GA evaluated the differences between the full arc and VMAT treatment plans with a limited gantry rotation angle. The VMAT treatment plan with the least effect of rectal gas was the full arc, and it was found that the shorter the gantry rotation angle range, the higher the effect of rectal gas on the dose distribution. The dose distribution among the four treatment planning techniques is the same from the DVH shape of CTV, and OAR was shown in Fig. 1, and the dose distribution shown in Fig. 2. Fig. 2 shows that when the gantry rotation angle is limited, and the CTV coverage is to be ensured, the dose distribution in the direction in which no photons enter is reduced without being enlarged. Therefore, the dose distribution becomes steep from the back of the CTV to the anterior wall of the rectum and the horizontal direction. It is thought that the steep dose distribution is greatly influenced by scattered radiation due to the presence and absence of rectal gas.

However, when investigating the effects of rectal gas, this study simulated the overwriting of the HU value in the overlap region and assumed that there was no positional displacement or deformation of CTV and OAR. In fact, during treatment, CTV and OAR are displaced and deformed due to rectal stool, gas, and urine capacity of the bladder. Therefore, it is necessary to evaluate the effect on the dose distribution in the case of positional displacement and deformation in CTV and OAR in the future.[15] It is also reported that the dose calculation algorithm used in this study, AAA, does not accurately calculate the change in density in non-uniform regions.[16] Therefore, the dose to the anterior wall of the rectum may be overestimated, and the dose to the posterior wall of the CTV may be underestimated. In the future, the dose calculation algorithm to be used will be studied using Acuros XB[17] or XVMC,[18] which is equivalent to the Monte Carlo simulation.

To the best of our knowledge, our study is pioneering for investigating the dose effect of rectal gas at each treatment in prostate VMAT. Therefore, the present study shows that the improved performance with full arc irradiation compared to partial irradiation in the presence of rectal gas, leads to a better understanding when performing prostate VMAT.

6. Conclusions

In this study, we investigated the effect of rectal gas on dose distribution during prostate cancer using a VMAT treatment plan. Specially, we investigated the impact of rectal gas on a variety of VMAT treatment plans with a partial limitation of full arc and gantry rotation angles. The VMAT treatment planning with the least effect on dose distribution caused by rectal gas was shown to be the full arc.

Conflict of interest

None declared.

Financial disclosure

None declared.

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