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Dosimetric Comparison of Volumetric Modulated Arc Therapy (VMAT), 5F Intensity Modulated Radiotherapy (IMRT) and 3D Conformal Radiotherapy (3DCRT) in Rectal Carcinoma Receiving Neoadjuvant Chemoradiotherapy

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Abstract

Objective: To investigate better dosimetric distribution of volumetric modulated arc therapy (VMAT) vs. 5F intensity modulated radiotherapy (IMRT) and 3D conformal radiotherapy (3DCRT) in patients with locally advanced rectal cancer (LARC) when treated with neoadjuvant chemoradiotherapy. Methods: 3D-CRT, 5F-IMRT and VMAT plans for preoperative radiotherapy were designed in 12 patients with locally advanced rectal cancer. The conformity index (CI) and homogeneity index (HI) in target volume, and the dose and volume of the organs at risk (OAR) irradiated including small bowel, bladder and bilatera1 femoral heads were compared among the three plans. Results: The CI for planning target volume (PTV) 2 and HI for PTV1 of VMRT and 5F-IMRT were superior to 3D-CRT. The CI of VMAT, 5F-IMRT and 3D-CRT plans were 0.71, 0.69 and 0.62 (p = 0.011 and p = 0.019, respectively). The HI of the VMAT and 5F-IMRT plans were both 1.04 and 3D-CRT planning was 1.06 (p = 0.022 and p = 0.006, respectively). The V_{35} - V_{45} of small bowel

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in VMAT were significantly less than in 5F-IMRT and 3D-CRT. V_{35} was 47.0, 56.4, and 72.8 cm^3 for VMAT, 5F-IMRT, and 3D-CRT (p = 0.021 and p = 0.034, respectively), while V_{40} was 30.5, 35.5, 45.1 cm^3 (p = 0.024 and p = 0.032, respectively) and V_{45} was 15.1, 18.1, 30.0 cm^3 (p = 0.033 and p = 0.032, respectively). The D_5, V_{30} and V_{50} of bladder in 3D-CRT were less than in VMAT and 5F-IMRT planning (p = 0.034, 0.004, 0.002 and p = 0.027, 0.003, 0.002, respectively). The D_{mean} of left femoral head in VMAT and 5F-IMRT were less than in 3D-CRT planning (p = 0.028 and p = 0.022, respectively) and the D_{mean}, V_{30} of right femoral head in VMAT and 5F-IMRT were better than in 3D-CRT planning (p = 0.044, 0.036 and p = 0.023, 0.028, respectively). Conclusions: Dosimetric analyses demonstrated that IMRT is superior to 3D-CRT in the conformity and homogeneity of dose distribution to the target volume, and provide a better protection to OARs sparing in patients with locally advanced rectal cancer for preoperative radiotherapy. With similar target coverage, VMRT is superior to 5F-IMRT in normal tissue sparing.

Keywords

Rectal Cancer, Preoperative Radiotherapy, Dosimetry, Conformity Index, Homogeneity Index

1. Introduction

Colorectal cancer remains a major worldwide health problem. It is the third most commonly diagnosed cancer in males and the second in females, with approximately 1.2 million new cases and 608,700 deaths per year. Environmental and dietary factors have been established as contributing to colorectal cancer [1]. In three-quarters of cases, the disease will be localized to the primary site with locally advanced rectal cancer (LARC). For these patients, neoadjuvant chemoradiotherapy followed by total mesorectal excision (TME) is the standard regimen [2] [3]. It has been reported that preoperative neoadjuvant chemoradiotherapy not only decreases the local recurrent probability, but also increases the anus preservation rate when compared to postoperative chemoradiotherapy [4].

Three-dimension conformal radiotherapy (3D-CRT) still remains as the main modality of radiotherapy for patients with rectal cancer in many institutes; the gastrointestinal toxic reaction, especially the acute and late toxicity of the bowel in the irradiated pelvic area, impair the patients' quality of life and recovery from radiation. Radiotherapy combined with neoadjuvant chemotherapy will increase the risk of toxicity [5]. Sauer, R. *et al.* [2] have showed that the incidence of grade 3/4 acute and late toxicity incidence were 12% and 9%, respectively when LARC patients received preoperative chemoradiotherapy and TME. Robertson, J.M. *et al.* [6] have demostated that development of Grade 3+ small bowel toxicity was significantly higher when patients with rectal cancer irradiated with larger volume of small bowel during chemoradiotherapy. How to increase the radiation dose in the target volume and decrease the dose and volume irradiated to the organs at risk such as small bowel and bladder, in order to improve the quality of life in patients with LARC who received preoperative chemoradiotherapy, is still in the further investigation. These findings have led to recommendations to consider IMRT as a choice of treatment planning technique to minimize small bowel toxicity.

The present study is to explore optimal radiotherapy delivery during neoadjuvant chemoradiotherapy to patients with LARC through comparing the dosimetry of 3D-CRT, 5-field intensity modulated radiotherapy (5F-IMRT), and volumetric modulated arc therapy (VMAT).

2. Materials and Methods

2.1. Patient Characteristics

Twelve consecutive patients with LARC underwent neoadjuvant chemoradiotherapy at Sun Yat-sen University Cancer Center from January 2012 to July 2012 were enrolled for the study, and all patients had signed informed consent. There were six males and six females. The median age was 57 years (range 31 - 73 years). All patients were diagnosed pathologically as adenocarcinoma. Six patients were staged as $cT_{2\text{-}4b}N_0M_0$ and the other six as $cT_{3\text{-}4b}N_{1a\text{-}1b}M_0$ according to the AJCC/UICC TNM (2010) staging system. The median length of tumor was 3.5 cm (range from 2 cm to 11 cm) and the median distance to anal verge was 5 cm (range from 1 cm to 10 cm). One patient had cervix invaded and one patient had the posterior of vaginal wall invaded.

2.2. CT Simulation

A concentration of 300 mgI/mL contrast (Niopam, Bracco, Milan, Italy) was diluted with saline to 800 ml. Each patient take diluents four times before the CT simulation (12 h, 8 h, 4 h and Pro Scan, respectively), 200 ml for each time. Patients were immobilized in the prone position on the carbon fiber belly board (Orfit, Belgium) with individualized thermoplastic. On the basis of the diagnosis with CT or MRI, reference points (0˚, 90˚, and 270˚) were marked on the positioning film with crosses after laser alignment, as close to the surface corresponding to the target area. Record the type of abdominal support and the coordinates of reference points for laser lights on the belly board (remain the same on both sides). The non contrast-enhanced and contrast-enhanced planning CT scans were obtained accordingly using spiral CT scanner (Brilliance Big Bore, Philips) with the scan range extended from the inferior aspect of L2 to 5 cm below the lower edge of the obturator; while the images were constructed and then imported to the treatment planning system (TPS).

2.3. Delineation of Target Volume and OAR

Target volume was defined according to the recommendations of the ICRU reports No. 50 and 62 and Myerson, R.J. *et al*. [7]. The gross tumour volume (GTV) was delineated further according to the information obtained from the diagnostic CT and MRI, including the rectal primary tumor and invaded lymph nodes. Two clinical target volumes (CTVs) were defined: CTV1 was the GTV plus the corresponding mesorectum and presacral region plus a margin of 2 - 5 cm in the cranio-caudal direction. CTV2 included the whole rectum and loco-regional lymph nodes at risk of involvement including internal iliac, obturator, presacral and part of the external iliac lymph nodes. The sacral foramina, coccyx and at least 1cm into the posterior bladder were formally included at mid and lower pelvis slices. The posterior part of prostate and seminal vesicles in male patients and the posterior of vaginal wall and cervix in female patients were also included in CTV2. The uppermost border for CTV2 was at the bifurcation of abdominal aorta approximated the sacral promontory and its lowermost border was at the anal verge covered the rectosigmoid junction and the whole rectum with its mesentery. PTV1, PTV2 were obtained by adding non-uniform margins to CTV1, CTV2 as below: the margins of the cranio-caudal, the anterior and posterior, and the lateral were 0.9 cm, 0.7 cm and 0.8 cm, respectively. The organs at risk (OAR) volumes were outlined in the small bowel, the bladder, and the femoral heads. The small bowel was outlined 3 cm above the PTV2, and the bladder was fully contoured.

2.4. Treatment Planning

For each patient, three sets of plans for 3D-CRT, 5F-IMRT and VMAT were generated for the dosimetric comparison. 3D-CRT plan was generated with ADAC Pinnacle3 8.0 (Holland) TPS; whereas the 5F-IMRT and VMAT plans were performed using the inverse planning system, (CMS mocano, version 2.0, Sweden). All plans were done using 8MV photons delivered by an Elekta ELE-1935. The 3D-CRT plan consisted of a three-field technique (one posterior and two lateral beams, dose ratio was 2:1:1) with wedge use to improve the target dose homogeneity. Radiation dose was prescribed as 46 Gy for PTV2 and a boost of 4 Gy to PTV1. The daily dose was delivered as 2.0 Gy per fraction. Fields were conformal shaped using the beam's eye view projections of the PTVs by means of a standard multi-leaf collimator. IMRT plans were generated using five coplanar equi-spaced fields (gantry angles 0˚, 72˚, 144˚, 2l6˚ and 288˚) with static multi-leaf collimator. The range of segments was set from 32 to 53. VMAT with single arc was delivered in a single 360˚ rotation. The isocenter was placed at the geometric center of the PTV2. The 5F-IMRT and VMAT treatment plans were designed to deliver in a single phase process (with simultaneously integrated boost, SIB) a dose of 46 Gy to the PTV2 in 23 fractions (2.0 Gy daily fractions) and at the same time 50 Gy to the PTV1 (2.17 Gy daily fractions). Once the treatment planning was completed, the plan was normalized to cover 100% of the PTVs with ≥95% of the prescribed dose. Planning objectives for OARs were defined as follows. Small bowel: minimal dose received by 5% of the volume (D_5) ≤ 50 Gy, max dose (D_{max}) ≤ 55 Gy. Bladder: $D_5 \leq 50$ Gy, $D_{max} \leq 55$ Gy. Femoral heads: $D_5 \leq 45$ Gy.

2.5. Plan Evaluation and Comparison

Dose Volume Histogram (DVH) was generated to evaluate the three different plans. For PTV, The degree of conformality was evaluated with a conformity index (CI) that was defined as $CI = (V_{PTV95\%} \times V_{PTV95\%})/(V_{body} \times V_{PTV})$, where $V_{PTV95\%}$ is the volume of the PTV receiving a dose equal to or greater than the 95% of the pre-

scribed dose, V_{body} is the volume receiving a dose equal to or greater than the 95% of the prescribed dose, V_{PTV} is the volume of the PTV [8]. Treatment plans with a CI greater than 0.60 might be termed conformal radiotherapy. Two conformity indexes, CI_{PTV1} and CI_{PTV2} were calculated both for the PTV1 and PTV2. The dose homogeneity to the PTV was expressed by the homogeneity index (HI) defined as $HI = D_{5\%}/D_{95\%}$, where $D_{5\%}$ and $D_{95\%}$ correspond to the dose delivered to 5% and 95% of the PTV, respectively [9]. Greater HI values indicated doses exceeding the prescription dose and, thus, a greater degree of dose heterogeneity in the PTV. HI_{PTV1} and HI_{PTV2} were calculated both for the PTV1 and PTV2. Mean dose (D_{mean}) and D_{max} were also reported.

For OARs, Small bowel and bladder avoidance was evaluated using the following parameters: D_5, D_{mean} and the absolute organ volume receiving doses at various levels (V_{30}, V_{35}, V_{40}, V_{45}, and V_{50}). Femoral heads were evaluated by D_{mean}, D_{max}, V_{30} and V_{40}.

2.6. Statistical Analysis

Statistical comparisons were performed using SPSS 16.0 for Windows. Comparisons between groups were tested by One-Way ANOVA analysis, and results were considered statistically significant for $p < 0.05$.

3. Results

3.1. Target Coverage, Conformality, and Dose Homogeneity

All plans met the prescription goal of ≥95% of the prescribed dose cover 100% of the PTVs and all the planning objectives were achieved with the three plans. **Table 1** list the Dmean and Dmax values for the target volumes. The D_{mean} and D_{max} were found to be significantly higher for both IMRT plans than for 3D-CRT planning ($p < 0.001$).

Table 2 shows the results for PTV in terms of conformity and dose homogeneity. Three plans were equivalent for conformality of PTV1 and dose homogeneity of PTV2. Both IMRT planning had the higher level of conformality in PTV2 compared to the 3D-CRT planning. The average CI of the VMAT and 5F-IMRT plans were 0.71 and 0.69, respectively, and the average CI of 3D-CRT planning was 0.62, ($p = 0.011$ and $p = 0.019$, respectively). **Figure 1** shows the isodose distributions across the target volumes with the three treatment modalities. Finally, the dose distribution across the PTV1 was less homogeneous after 3D-CRT planning than after VMAT or 5F-IMRT planning. The average HI of the VMAT and 5F-IMRT plans were both 1.04, and the average HI of 3D-CRT planning was 1.06 ($p = 0.022$ and $p = 0.006$, respectively). DVHs of the target volumes with the three different techniques are shown in **Figure 2**.

3.2. Organs at Risk

In **Table 3**, the numerical findings from DVH analysis on main OARs (small bowel, bladder and femoral heads) are reported. **Figure 2** shows the average DVHs for OARs.

3.2.1. Small Bowel

The median volume of the small bowel contoured in the 12 patients was 551.9 cm^3 (range, 126.4 cm^3 to 916.9 cm^3). The DVH parameters (D_5, D_{mean} and V_{30}) were similar for the three plans. However, V_{35}, V_{40} and V_{45} were significantly smaller after VMAT planning than after 5F-IMRT and 3D-CRT planning. V_{35} was 47.0, 56.4, and 72.8 cm^3 ($p = 0.021$ and $p = 0.034$, respectively) for VMAT, 5F-IMRT, and 3D-CRT, while V_{40} was 30.5, 35.5, 45.1 cm^3 ($p = 0.024$ and $p = 0.032$, respectively) and V_{45} was 15.1, 18.1, 30.0 cm^3 ($p = 0.033$ and $p = 0.032$, respectively).

3.2.2. Bladder

The median volume of the bladder contoured was 524.5 cm^3 (range, 211.7 cm^3 to 823.6 cm^3). No significant difference between the three plans was noted for the parameters V_{35}, V_{40}, V_{45} and mean dose. However, from details numerical findings of DVH graphs, it can be noticed that 3D-CRT was superior to VMAT and 5F-IMRT for the parameters D_5, V_{30}, and V_{50}. For VMAT, 5F-IMRT, and 3D-CRT, D_5 was 5100.6, 5107.6, and 4901.0 cGy, respectively ($p = 0.034$ and 0.027), V_{30} was 456.1, 463.5, and 365.8 cm3, respectively ($p = 0.004$ and 0.003), while V_{50} was 57.5, 57.5, 23.3 cm^3, respectively ($p = 0.002$ and 0.002).

Table 1. Dose comparison for planning target volumes (PTVs) (mean ± standard deviation).

	VMAT (cGy)	5F-IMRT (cGy)	3D-CRT (cGy)	*F*	*P*	*P*1	*P*2	*P*3
$PTV1_{Dmean}$	5223.4 ± 35.1	5201.4 ± 34.8	5060.0 ± 39.5	70.538	<0.001	0.450	<0.001	<0.001
$PTV1_{Dmax}$	5473.5 ± 82.4	5511.0 ± 57.6	5289.8 ± 56.3	37.913	<0.001	0.531	<0.001	<0.001
$PTV2_{Dmean}$	5029.9 ± 50.8	5015.3 ± 62.5	4928.9 ± 57.3	10.976	<0.001	1.000	<0.001	0.001
$PTV2_{Dmax}$	5473.5 ± 82.4	5516.7 ± 52.8	5299.4 ± 58.6	36.548	<0.001	0.354	<0.001	<0.001

VMAT: volumetric modulated arc therapy; IMRT: intensity modulated radiotherapy; 3D-CRT: three-dimensional conformal radiotherapy; CI: conformity index; HI: homogeneity index; PTV: planning target volume; *P*1: VMAT vs. 5F-IMRT; *P*2: VMAT vs. 3D-CRT; *P*3: 5F-IMRT vs. 3D-CRT.

Table 2. Comparison of conformity and homogeneity for planning target volumes (PTVs) (mean ± standard deviation).

	VMAT	5F-IMRT	3D-CRT	*F*	*P*	*P*1	*P*2	*P*3
CI_{PTV1}	0.37 ± 0.09	0.37 ± 0.09	0.36 ± 0.08	0.076	0.927			
CI_{PTV2}	0.71 ± 0.06	0.69 ± 0.05	0.62 ± 0.07	6.103	0.006	1.000	0.011	0.019
HI_{PTV1}	1.04 ± 0.01	1.04 ± 0.01	1.06 ± 0.01	5.980	0.006	1.000	0.022	0.006
HI_{PTV2}	1.13 ± 0.01	1.12 ± 0.02	1.12 ± 0.02	1.284	0.291			

VMAT: volumetric modulated arc therapy; IMRT: intensity modulated radiotherapy; 3D-CRT: three-dimensional conformal radiotherapy; CI: conformity index; HI: homogeneity index; PTV: planning target volume; *P*1: VMAT vs. 5F-IMRT; *P*2: VMAT vs. 3D-CRT; *P*3: 5F-IMRT vs. 3D-CRT.

Table 3. Comparison of radiation dose and volume for organs at risk (mean ± standard deviation).

	VMAT	5F-IMRT	3D-CRT	*F*	*P*	*P*1	*P*2	*P*3
Small bowel								
D_5 (cGy)	3753.2 ± 768.3	3928.0 ± 673.0	3990.0 ± 953.1	0.278	0.759			
Dmean (cGy)	1692.5 ± 413.0	1744.7 ± 395.9	1664.6 ± 533.4	0.097	0.908			
V_{30} (cm^3)	80.4 ± 68.1	93.2 ± 64.4	115.6 ± 111.8	0.527	0.596			
V_{35} (cm^3)	47.0 ± 43.7	56.4 ± 45.4	72.8 ± 78.6	0.602	0.008	0.021	0.034	0.259
V_{40} (cm^3)	30.5 ± 31.3	35.5 ± 34.2	45.1 ± 48.8	0.437	0.049	0.024	0.032	0.092
V_{45} (cm^3)	15.1 ± 18.0	18.1 ± 21.7	30.0 ± 34.7	1.127	0.036	0.033	0.032	0.054
V_{50} (cm^3)	0.16 ± 0.47	0.14 ± 0.39	3.50 ± 11.12	1.043	0.319			
Bladder								
D_5 (cGy)	5100.6 ± 115.8	5107.6 ± 123.7	4901.0 ± 265.9	4.979	0.013	1.000	0.034	0.027
Dmean (cGy)	4141.9 ± 303.1	4212.8 ± 350.0	3939.9 ± 440.5	1.767	0.187			
V_{30} (cm^3)	456.1 ± 154.1	463.5 ± 167.8	365.8 ± 139.2	8.596	0.001	1.000	0.004	0.003
V_{35} (cm^3)	387.5 ± 138.5	412.3 ± 151.1	341.5 ± 134.7	2.541	0.094			
V_{40} (cm^3)	313.6 ± 127.6	342.3 ± 134.6	318.0 ± 130.9	0.547	0.584			
V_{45} (cm^3)	214.4 ± 88.2	236.2 ± 100.6	282.6 ± 127.4	2.491	0.098			
V_{50} (cm^3)	57.5 ± 34.1	57.5 ± 40.1	23.3 ± 27.2	3.853	0.003	1.000	0.002	0.002
Left femoral head								
Dmean (cGy)	2955.5 ± 489.5	2919.2 ± 468.8	3400.9 ± 567.3	3.315	0.049	1.000	0.028	0.022
V_{30} (%)	42.0 ± 26.2	42.9 ± 22.7	64.0 ± 30.5	2.607	0.089			
V_{40} (%)	12.6 ± 12.2	14.5 ± 12.7	24.9 ± 27.1	1.510	0.236			
Right femoral head								
Dmean (cGy)	2932.1 ± 446.3	2848.5 ± 435.8	3410.0 ± 560.7	4.696	0.016	1.000	0.044	0.023
V_{30} (%)	40.1 ± 24.5	39.1 ± 21.6	67.5 ± 28.8	4.898	0.014	1.000	0.036	0.028
V_{40} (%)	11.7 ± 11.9	12.8 ± 10.8	26.1 ± 24.3	2.709	0.081			

VMAT: volumetric modulated arc therapy; IMRT: intensity modulated radiotherapy; 3D-CRT: three-dimensional conformal radiotherapy; CI: conformity index; HI: homogeneity index; PTV: planning target volume; *P*1: VMAT vs. 5F-IMRT; *P*2: VMAT vs. 3D-CRT; *P*3: 5F-IMRT vs. 3D-CRT.

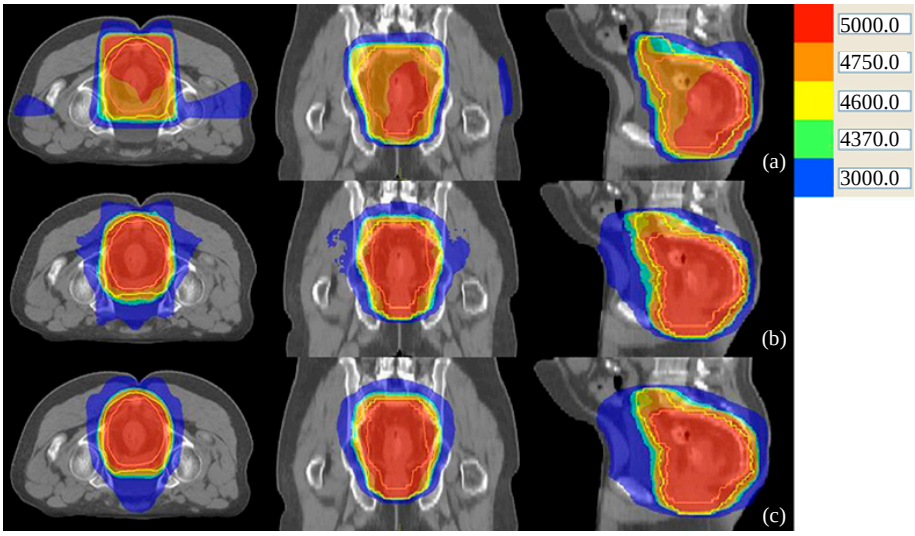

Figure 1. Dose distributions for one representative patient (male, 48 years, stage IIIB for T3N1M0, the distance was 5 cm from tumor to anal verge). (a) Axial, coronal and sagittal views for 3D-CRT; (b) Axial, coronal and sagittal views for 5F-IMRT; (c) Axial, coronal and sagittal views for VMAT; orange contour: PTV1; yellow contour: PTV2.

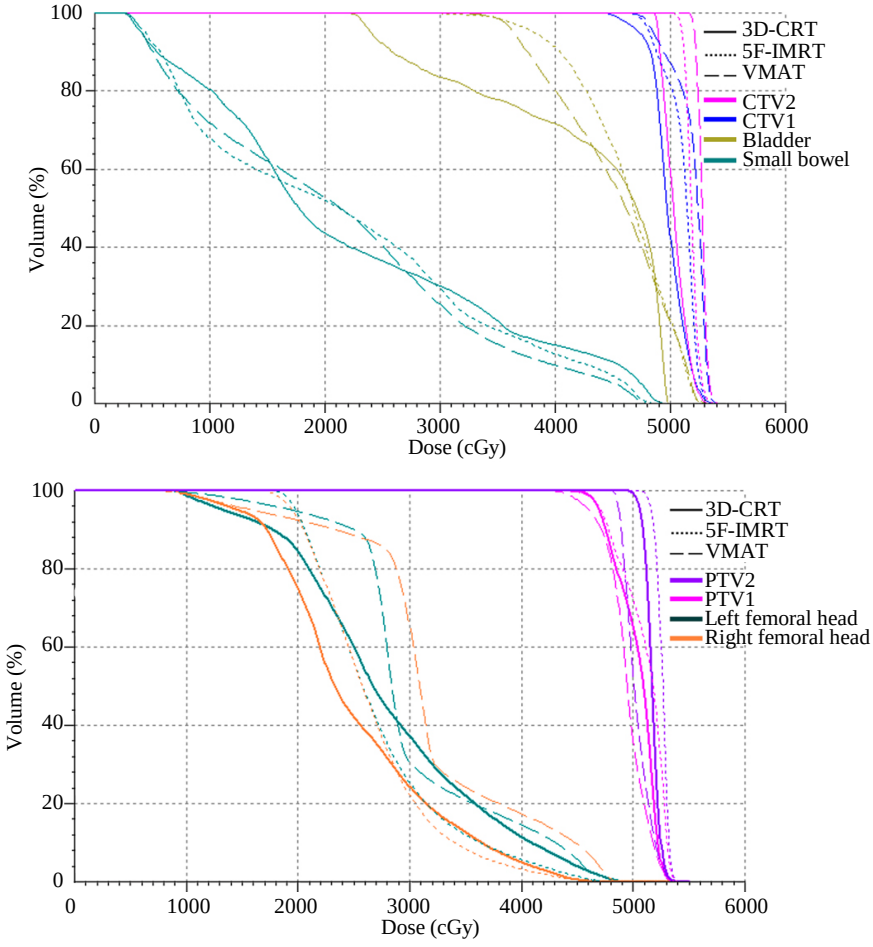

Figure 2. Dose Volume Histogram (DVH) for one representative patient with rectal carcinoma. VMAT: volumetric modulated arc therapy; IMRT: intensity modulated radiotherapy; 3D-CRT: three-dimensional conformal radiotherapy; CTV: clinical target volume; PTV: planning target volume.

3.2.3. Femoral Heads

Planning objectives ($D_5 \leq 45$ Gy) were met by all techniques and D_{max} did not exceed 50 Gy in all patients. IMRT planning produced significantly lower mean dose values for left femoral head. For VMAT, 5F-IMRT, and 3D-CRT, D_{mean} was 2955.5, 2919.2, and 3400.9 cGy, respectively ($p = 0.028$ and 0.022). While, D_{mean}, V_{30} were significantly lower after IMRT planning than after 3D-CRT planning for right femoral head. For VMAT, 5F-IMRT, and 3D-CRT, D_{mean} was 2932.1, 2848.5, and 3410.0 cGy, respectively ($p = 0.044$ and 0.023), V_{30} was 40.1, 39.1, and 67.5 cm^3, respectively ($p = 0.036$ and 0.028).

4. Discussion

VMAT is a promising technique, providing efficient and precise irradiation to target volume with linear accelerator rotating a perfect 360˚ arc [10]. When compared with conventional IMRT, VMAT was investigated for various types of tumors in pelvic with significant improvements in organs at risk sparing with uncompromised target coverage leading to better conformal avoidance of treatments, while it could reduce significantly the treatment time and the number of monitor units (MU) required [11]-[13]. Owing to a few studies have been addressed on the use of VMRT in rectal cancer, the present study was designed to compare the degree of target coverage and target dose distribution, conformality, and normal tissue avoidance in VMAT, 5F-IMAT, and 3D-CRT.

Our data confirmed that VMAT and 5F-IMAT achieve better results than 3D-CRT in terms of conformity and homogeneity in PTV with higher D_{mean} and D_{max} in target volumes, which is very similar to other studies that IMRT planning has superior target conformity and homogeneity to 3D-CRT by increasing the target volume dose with a better organs at risk and healthy tissue sparing [12] [14] [15].

Small bowel is the most important dose-limited organs in the setting of radiotherapy to rectal cancer. Radiotherapy might cause the acute and late toxicities such as diarrhea, dyspepsia, intestinal obstruction or perforation, and so on [16]. Gunnlaugsson, A. *et al.* [17] demonstrated a strong correlation between the occurrence of Grade 2+ diarrhoea and the irradiated small bowel volume in twenty-eight patients with LARC when treated with 5-FU-OXA based chemoradiotherapy. Their research showed that the incidence of significant diarrhea was 11% when the volume of small bowel irradiated was ≤150 cm^3 at dose level > 15 Gy and 52% when the volume > 150 cm^3. Devisetty, K. *et al.* [18] have tried to identifying bowel dosimetric parameters associated with gastrointestinal toxicity in anal cancer patients with chemoradiotherapy. They found higher acute gastrointestinal toxicity for V30 > 450 cm^3 and ≤ 450 cm^3 (33% vs. 8%, $p = 0.003$). In this study we did not demonstrate a significant difference in the V_{30} to the small bowel between the IMRT and 3D-CRT planning techniques. But the V_{35} - V_{45} of small bowel in VMAT were significantly less than that in 5F-IMRT and 3D-CRT. Cilla, S. *et al.* [15] showed that VMAT is associated with 40%, 53% and 58% reduction in the percentage of volume of small bowel irradiated to 30 Gy, 40 Gy and 50 Gy compared with 3D-CRT. No significant differences were found between VMAT and 7-field SIB-IMRT. Samuelian, J.M. *et al.* [19] observed that IMRT can significantly reduce the acute gastrointestinal toxicity with incidence of 32% patients experiencing Grade 2+ acute gastrointestinal effects, compared with 62% among 3D-CRT patients ($p = 0.006$). Our study is similar to Cilla, S. *et al.* [15] that the V_{30} of small bowel is much less than 450 cm^3 which may be as result to prone position and use of Orfit belly board. Cranmer-Sargison, G. *et al.* [20] showed that the belly board provides excellent small bowel sparing regardless of planning technique. In most cases, IMRT reduced the average femoral head, bladder and small bowel dose by 20%, 15% and 40% with respect to 3DCRT planning.

This research indicates that compared with 3D-CRT, the V_{30} of bladder in 5F-IMRT and VMAT is much higher which may be the result of the enlarging area of low dose due to the increase of modulated fields [21]. In this study, the D_5 and V_{50} of bladder in 3D-CRT were lower than 5F-IMRT and VMAT, probably due to the dose is mainly distributed on the rear side as a result of the technique of delivering a boost dose of 4 Gy for PTV1 alone by narrowing the field after PTV2 irradiated 46 Gy and the three-field technique (one posterior and two lateral beams, dose ratio was 2:1:1). In addition, compared with other pelvic organs, bladder is more tolerance irradiated organs and the TD 5/5 for whole and 2/3 volume irradiation were 65 Gy and 80 Gy, respectively [22]. Studies have shown that the incidence of Grade 3/4 bladder toxicity was only 1% to 2% [10] [23]. 5F-IMRT and VMAT showed a clear advantage in terms of femoral heads sparing at D_{mean} and V_{30} with respect to 3D-CRT, which may reduce the probability of occurrence of avascular necrosis.

5. Conclusion

In summary, our findings indicate that IMRT is superior to 3D-CRT in the conformity and homogeneity of dose distributing to the target volume, and provide a better protection to OARs sparing in the LARC patients with preoperative radiotherapy in the condition of using a carbon fiber belly board plus individual thermoplastic positioning film. VMRT can further reduce the volume and dose irradiated to the small bowel, and bladder thereby reduces the treatment toxicity and improves the patient's quality of life.

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Abbreviations Table

Abbreviations	Full meanings
LARC	locally advanced rectal cancer
TME	total mesorectal excision
VMAT	volumetric modulated arc therapy
IMRT	intensity modulated radiotherapy
3D-CRT	three-dimensional conformal radiotherapy
CI	conformity index
HI	homogeneity index
GTV	gross tumour volume
CTV	clinical target volumes
PTV	planning target volume
OAR	organs at risk
TPS	treatment planning system
DVH	dose volume histogram
D_5	minimal dose received by 5% of the volume
D_{max}	max dose
D_{mean}	mean dose
MU	monitor units

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