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DOSIMETRIC COMPARISON OF VMAT AND 3D CONFORMAL RADIOTHERAPY IN PREOPERATIVE RECTAL CANCER

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Abstract:

The standard procedure in treating rectum cancer is surgical intervention, but presurgical chemotherapy and radiotherapy lead to a lower rate of localized recidives. Our study compared the results obtained by two techniques of radiation treatment planning (RTP) in radiotherapy, which patients received in the preoperative course of rectum cancer treatment, Volumetric Modulated Arc Therapy (VMAT) and field-in-field three-dimensional conformal radiotherapy (FIF 3D-CRT). We analyzed better coverage of the planning target volume (PTV) and better protection of organs from risk (OAR): bladder, bowel, left femoral head, and right femoral head results and monitor unit (MU). Also, we analyzed the target volume coverage indicators included homogeneity index (HI), and conformity index (CI). Selected five patients were treated in University Clinical Center Kragujevac during 2020. The two types of techniques for making radiotherapy plans, mentioned above, were designed for each patient using the same CT scans. All plans were done on the treatment planning system ECLIPSE-Version 15.6 (Varian). The prescribed dose for all patients was 50 Gy in 25 fractions. The first arc was planned in the clockwise direction and the second in the counter clockwise direction. FIF 3D-CRT plans were obtained by using fields from four different directions with the same isocenter. It was obtained that VMAT plans, compared to the FIF 3D-CRT, achieved better coverage of the PTV (D95%), better heterogeneity, and conformity. Protection for OAR such as the bladder, femoral heads, and small bowel is much better than that given by FIF 3D-CRT plans. However, the number of MU calculated by FIF 3D-CRT is almost twice lower compared to VMAT.

Key words: rectal cancer, radiotherapy, radiation treatment planning (RTP), VMAT technique, FIF 3D-CRT technique.

1. Introduction

Rectal cancer is still one of the most common malignancies. Based on data downloaded from the Global Cancer Observatory website, that the number of diagnosed cases of rectal cancer in 2020. was

1.931.590 (10% of all of the diagnosed cancer cases). The number of deaths was 935.173 (9.4%) [1]. The standard procedure in treating rectum cancer is surgical intervention, which implies a total mesorectal excision [2]. Application of presurgical chemotherapy and radiotherapy leads to a lower rate of localized recidives. Good optimization strategies can treat the target volume and, at the same time, reduce as much as possible the dose receiving by organs at risk (OAR). Protecting the small bowel is very important because the secondary effect associated with pelvic radiotherapy for rectal cancer is gastrointestinal toxicity [3]. 3D-CRT uses four fields (two laterals and AP/PA), MLC-s field-in-field techniques, and wedges. Due to the concave shape of the target volume, the application of this technique does not provide good enough protection for the bladder and small bowel. VMAT is a technique by which a certain dose of radiation is continuously delivered while the gantry of the linear accelerator is rotating. Given the method of delivery of the prescribed dose, it is expected that the VMAT technique will better spare OAR and gave better coverage and isodose conformation of the target volumes [4]. This study shows the plans comparison of FIF 3D-CRT and VMAT technique and the advantages and disadvantages of one technique compared to another by observing plans results.

2. Methods and results

All observed patients had locally advanced rectal cancers. CT simulation was performed in the pronation position with basic immobilization (CIVCO Medical Solutions). CT scans were made of CT GE Discovery with 2.5 mm of slice thickness. Patients are instructed to have a comfortably full bladder before the CT scanning and before receiving each fraction of radiotherapy treatment. In this way, the dose received by the bladder and small bowel is reduced. The oncologist delineated the clinical target volumes (CTV). CTV contains gross tumor volume (GTV) with the mesorectal region near the tumor, with a margin of 2–3 cm, pelvis' posterior wall, and internal iliac lymph nodes. PTV was generated by adding a 1 cm margin to the CTV. As organs at risk, the oncologist marked the bladder, small bowel and femoral heads. The small bowel was outlined to 1 cm above the PTV.

The prescribed dose was 50 Gy in 25 fractions. The primary objective for the PTV volume was to achieve 95% of the dose to cover at least 98% of the PTV volume. The acceptability of plans is determined by respecting the OAR constraints: bladder (constraint V46<80%), small bowel (constraint V40<80% and V40<150cc), and femoral heads (constraint V46<80%). 3D–CRT plans were obtained by using four isocentric fields with different directions (270°, 0°, 90°, 180°) along with field-in-field technique (Fig. 1 (left pane)).

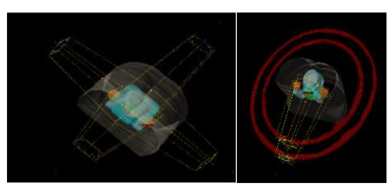

Fig. 1. 3D-CRT (left pane) and VMAT (right pane) field arrangements.

MLC margin was 0.6 cm for all of the fields. Dose distributions were calculated with 10 MV photon beams. Two full ARCs were applied in VMAT planning. Isocenter was positioned in the centre of the target volume (PTV). The size of the field and the angle of the collimator were adjusted with the option Arc geometry tool (Fig. 1 (right pane)). Dose Volume Histogram (DVH) of VMAT plans for patients were evaluated and compared to the DVHs of the corresponding 3D-CRT plans. The conformity index (CI) is a measure of target coverage and the conformity of the high dose region to the PTV, and it is defined as $CI=V_{95\%isodse}/V_{PTV}$ [5]. Perfect conformance is CI=1, lower values means poorer plan quality. The homogeneity index HI was calculated $HI=(D_{2\%PTV}-D_{98\%PTV})/D_{50\%PTV}$ [6], $Dx\%_{PTV}$ (Gy) is a minimal dose that is received by x% of the volume of the PTV. $D_{2\%}$ is also known as D (near-max), and $D_{98\%}$ is D (near-mean). $D_{50\%PTV}$ (Gy) is the median dose of the PTV. Smaller values of HI indicate better dose homogeneity in the PTV. Dose distributions obtained with 3D-CRT and VMAT techniques for one of the patients in this study were shown in Fig. 2, where the superiority of the VMAT technique can be seen. The results of the VMAT plans show a highly significant improvement in the CI and HI and reduction in the $D_{2\%}$ and $D_{50\%}$ in PTV over 3D-CRT plans (Table 1).

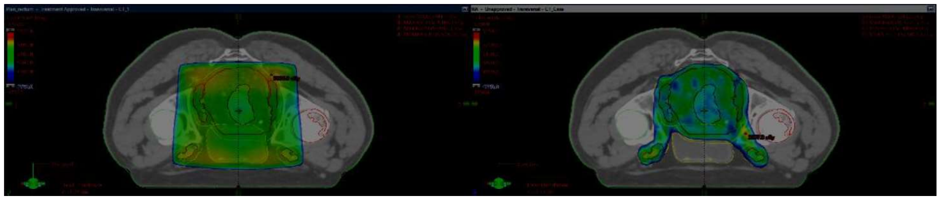

Fig. 2. Dose distribution for 3D-CRT (left pane) and VMAT (right pane) plans.

Table 1. Results of the calculated dosimetric parameters according to the delivery technique.

Patient	PTV									
	FIF 3D CRT					VMAT				
	HI	CI	$D_{2\%}$[cGy]	$D_{50\%}$[cGy]	$D_{98\%}$[cGy]	HI	CI	$D_{2\%}$[cGy]	$D_{50\%}$[cGy]	$D_{98\%}$[cGy]
1	0,08	1,54	5.226,80	5.015,30	4.818,30	0,05	1,09	5.119,70	5.011,60	4.845,20
2	0,08	1,54	5.271,60	5.103,20	4.852,70	0,05	1,11	5.109,50	5.009,50	4.863,00
3	0,10	1,97	5.289,10	5.041,90	4.798,40	0,06	1,16	5.114,60	5.009,00	4.838,10
4	0,09	1,70	5.273,30	5.077,90	4.835,00	0,05	1,12	5.112,50	5.007,40	4.866,50
5	0,08	2,10	5.247,70	4.975,00	4.833,60	0,05	1,20	5.108,70	4.993,40	4.845,90

Results showed that the maximum doses in VMAT plans were lower than in 3D-CRT for all patients. The volume covered by the 95% dose is approximately the same using both techniques. All the evaluated dosimetric parameters for OAR, except for the maximum dose for small bowel, were significantly different. These differences are shown in Fig. 3 for the bladder and small bowel. For the bladder, VMAT plans showed a mean reduction of 12.41 Gy in the mean dose and 53.94% in the V46 parameter in comparison with 3D-CRT plans (Table 3). VMAT plans yielded a 6.39 Gy mean reduction in mean dose for the small bowel over the entire dose range and the mean reduction for the V40 parameter of 19.22% and 22.36 cc. Mean Dose showed a decrease of the small bowel irradiated volumes over the entire dose range.

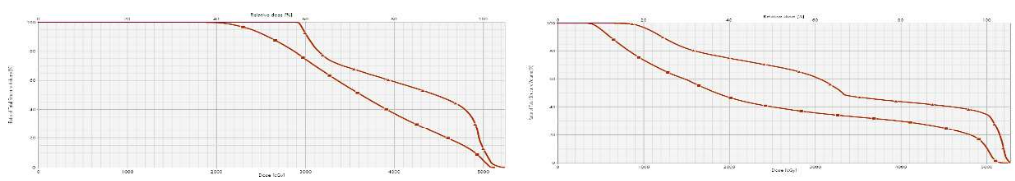

Fig. 3. DVH comparison for OARs. Line with triangles is for 3D-CRT and squares are for VMAT.

The femoral heads are the organs that showed the highest dose reduction when comparing 3D-CRT plans with VMAT plans. Mean reductions in the mean dose of 5.12 Gy in the right femoral head and of 8.97 Gy in the left femoral head were obtained. OAR dosimetric parameters, obtained using both techniques, are given in Table 2.

Table 2. Mean values across all plans of the dosimetric parameters of the OAR.

	Plan parameter	3D-CRT Mean (Gy)	VMAT Mean (Gy)	Difference		Plan parameter	3D-CRT Mean (Gy)	VMAT Mean (Gy)	Difference
Bladder	Dmean	47,03	34,62	12,41	Left femoral head	Dmean	35,55	26,58	8,97
	Dmax	52,65	51,58	1,07		Dmax	49,81	39,96	9,85
	V46 (%)	74,46	20,52	53,94		V46 (%)	20,18	0	20,18
Small bowel	Dmean	31,92	25,53	6,39	Right femoral head	Dmean	32,97	27,85	5,12
	Dmax	51,96	52,03	-0,07		Dmax	50,31	37,92	12,39
	V40 (%)	43,3	24,08	19,22		V46 (%)	14,16	0	14,16
	V40(cc)	55,09	32,73	22,36					

The number of MU for plans obtained with the 3D-CRT technique was (255, 244, 259, 271, 276), while the VMAT technique gave (583, 576, 600, 600, 599), the first numbers in both parentheses correspond to the first patient, the second for the second patient, and so on. The number of MU increased considerably in the arc therapy plans due to the continuous irradiation that characterizes this type of delivery.

4. Conclusions

We evaluated and compared dose parameters of the two different treatment planning processes, 3D-CRT and VMAT, analyzed the target volume coverage indicators CI and HI. Plans made with the VMAT technique produced better dosimetric results, the coverage and isodose conformation of the target volumes, and the sparing of organs at risk (OAR) than 3D-CRT.

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