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DOSIMETRIC COMPARISON OF VMAT AND IMRT TREATMENT PLANNING TECHNIQUES FOR PROSTATE CANCER

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PROSTAT KANSERİNDE VMAT VE IMRT TEDAVİ PLANLAMA TEKNİKLERİNİN DOZİMETRİK KARŞILAŞTIRILMASI

ABSTRACT

Aim: To compare the dosimetric endpoints (Conformity Index (CI), Planning Tumor Volume (PTV) and Organs at Risk (OARs) Doses) of the Volumetric Modulated Arc Therapy (VMAT) and Intensity Modulated Radiation Therapy (IMRT) for prostate cases.

Materials and methods: 20 prostate plans were generated with VMAT and IMRT: the prescribed dose was 74 Gy in 37 fractions. In the comparison, low dose region, monitor unit(MU), OARs reference doses, and tumor volume doses were used. Also, conformity of dose distributions was evaluated with the novel and universal CI algorithm.

Results: $V_{95\%}$, $V_{100\%}$, D_{mean} for PTV were similar in VMAT and IMRT plans. VMAT achieved lower doses to bladder for nearly all reference doses. However, IMRT had lower doses than VMAT for rectum. There wasn't clinically superiority between IMRT and VMAT in all OAR reference doses. But there was clinically and statistically significant differences in the conformity of dose distributions (Conformity for 95% relative dose in VMAT:81,9% and in IMRT:72,3%) ($p<0,001$). Also, VMAT achieved 35% decrease according to IMRT in the MU (Monitor Unit) with clinical and statistical significance ($p<0,001$). Moreover, VMAT had the superiority in the low dose region according to IMRT.

Conclusion: The superiority of VMAT over IMRT has been clearly demonstrated thanks to ideal, novel and universal Conformity Index algorithm. CI should be used as well as Dose Volume Histogram (DVH) for the selection of the best plan.

Key Words: Conformity Index, Dosimetric Evaluation, Prostate Cancer, IMRT, VMAT.

1. Introduction

Prostate cancer is one of the most common types of malignant diseases for men in the world. Considerable progress in treatment planning system (TPS) is achieved thanks to developments in computer technology. Current treatment planning techniques such as intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) improved significantly along with this progress. These are techniques used in the external body radiation therapy (EBRT) to treat cancer. Radiotherapy is one of the most important treatment options for prostate cancer and IMRT and VMAT radiotherapy treatment methods are used in general for these cases. In IMRT, multiple fixed angle radiation beams and a set of smaller segments of differing MLC shape is modulated by continuously moving multileaf collimators (MLC). One or multiple arcs are used in the VMAT treatment technique allowing the simultaneous variation in gantry rotation speed, dose rate, and MLC leaf positions (Otto, 2008, Teoh et al. 2011, Rana, 2013).

VMAT can decrease the treatment delivery time because VMAT has more beam entry angles, which likely contributes to the lower number of Monitor Units (MU) needed compared with the IMRT plan (Rana, 2013). MU and low dose results alone are not sufficient data for secondary cancer evaluation. But the increase in MU can increase the possibility of secondary cancers for peripheric healthy organs since it also increases the low dose distributions on the body. Also, secondary cancer risk can increase with increasing low dose region (0-20 Gray (Gy) at adjacent healthy tissues for cancer patients surviving 10 years or more such as pediatric cancer patients. Therefore, the magnitude of the low dose region should be evaluated while comparing the planning technique.

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Recently, interest in using VMAT has been increased. Several authors have done treatment planning studies comparing IMRT and VMAT for prostate cancer planning. According to DVH results, VMAT prostate plans were superior for Organs at Risk (OARs) doses. In addition, there wasn't any clinical and statistical significance in results for conformity of dose distributions. Also, Conformity Index (CI) results of studies are conflicting. Because existing CI formulas had some deficiencies. Due to these problems, differences between VMAT and IMRT plans have not been detected sufficiently.

The aim of this study is to show that VMAT plan can achieve better treatment plan dose distributions with statistical and clinical significance thanks to ideal, universal and novel Conformity Index tool resolving all existing problems. (Gonultas & Dirican 2022).

2. Materials and methods

2.1. Radiotherapy Treatment Planning

20 prostate plans were generated with VMAT and IMRT in Eclipse TPS using Acuros algorithm: the prescribed dose was 74 Gy in 37 fractions. The dosimetric endpoints of VMAT and IMRT plans were compared. In the comparison MU, OARs reference doses (Mean Dose, V_{40Gy}, V_{50Gy}, V_{60Gy}, V_{65Gy}, V_{70Gy} for Rectum; Mean Dose, V_{40Gy}, V_{50Gy}, V_{65Gy}, V_{70Gy} for Bladder; V_{45Gy},V_{50Gy} for Femoral Head (V_{DGy} (%): percent volume receiving the D Gy, for example V_{40Gy}(%): percent volume receiving 40 Gy)) and planning tumor volume (PTV) doses ($V_{95(\%)}$ (%), $V_{100(\%)}$ (%), mean dose for PTV ($V_{D\%}$ (%): percent volume receiving the D% of prescribed dose, for example $V_{95\%}$ (%); percent volume receiving 95% of prescribed dose))) were used. Also, conformity of dose distributions was evaluated with novel and universal CI algorithm. Moreover, the low dose region was evaluated with the CI-Relative Dose curves.

2.2. The Novel Universal Conformity Index Algorithms

Conformity Index algorithm should measure the conformity of tumor volume and healthy tissue volume with prescribed isodose volume. The most important radiotherapy aim is giving high dose to tumor volume while low dose to healthy tissue volume. But existing Conformity Index equalities don't take into account the tumor volume and healthy tissue volume. Thus the Conformity Index equalities are not ideal. For this problem, conformity index evaluations in existing studies fail to detect the difference between plans. If a researcher wants to detect the difference between plan dose distributions, one should use conformity Index algorithm as well as Dose Volume Histogram (DVH). To overcome problems of existing CI equality, the following CI equation was proposed (Gonultas & Dirican, 2022).

$$CI = \frac{TV_{PIV}}{TV + PIV - TV_{PIV}} \quad (1)$$

TV_{PIV}: Tumor volume covered by prescription isodose volume, TV: Tumor volume, PIV: Prescription isodose volume.

2.3. Statistical Analysis

In our study, t-test was used for statistical analysis. Before statistical analysis, power analysis was performed with the G-Power program, and the number of samples was determined as 20 (Fig. 1).

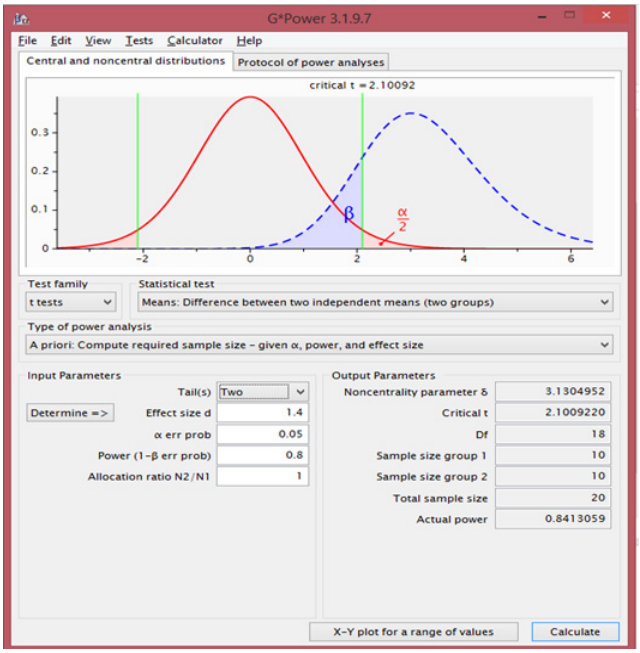

Figure 1. Outputs of power analysis.

3. Results

The dosimetric endpoints for PTV and OARs were summarized at the Table 1. $V_{95\%}$, $V_{100\%}$, D_{mean} for planning tumor volume (PTV) were similar in VMAT and IMRT plans. The VMAT plan PTV volume dose parameters $V_{95\%}$, $V_{100\%}$ and D_{mean} were 100%, 96,12% and 76,97 Gy, respectively. The IMRT plan PTV volume-dose parameters $V_{95\%}$, $V_{100\%}$ and D_{mean} were 100%, 96,80% and 76,70 Gy, respectively. There wasn't any statistical significance (p>0,05).

For the rectum, V_{40Gy}, V_{50Gy}, V_{60Gy}, V_{65Gy}, V_{70Gy} and V_{75Gy} dosimetric parameters listed in Table 1, IMRT technique achieved lower doses than VMAT. For the bladder, V_{40Gy}, V_{50Gy}, V_{65Gy}, V_{70Gy} dosimetric parameters listed in Table 1, VMAT technique achieved lower doses than IMRT. However, there wasn't any clinical superiority between IMRT and VMAT in all OAR reference doses. Also, IMRT and VMAT techniques had the same results for V_{45Gy}, V_{50Gy} reference doses for femoral heads. Also, VMAT technique achieved 35% decrease according to IMRT technique in the MU with clinical and statistical significance (p<0,001). According to DVH results,

Table 1. Summarization of the dosimetric endpoints for PTV and OARs. Abbreviations: Fx(Fraction), R(Right, L (Left)) PTV: Planning Tumor Volume, $V_{D\%}$(%): percent volume receiving the D% of prescribed dose, for example V95% (%); percent volume receiving 95% of prescribed dose, V_{DGy}(%): percent volume receiving the D Gy, for example V_{40Gy}(%): percent volume receiving 40 Gy, CI: Conformity Index.

	Patient 1		*Patient 2*		*Patient 3*		*Patient 4*		*Patient 5*		*Patient 6*		*Patient 7*		*Patient 8*		*Patient 9*		*Patient 10*		*MEAN*		*P-Value*
	IMRT	**VMAT**	**IMRT**	**VMAT**	**IMRT**	**VMAT**	**IMRT**	**VMAT**	**IMRT**	**VMAT**	**IMRT**	**VMAT**	**IMRT**	**VMAT**	**IMRT**	**VMAT**	**IMRT**	**VMAT**	**IMRT**	**VMAT**	**IMRT**	**VMAT**	
MU/FX	635	484	652	345	684	363	564	577	728	505	947	427	690	346	766	474	676	491	716	571	706	458	<0,001
CI*	82,9	82,5	65,1	79,6	75,7	81,4	73,8	83,3	74,0	84,2	72,2	83,5	74,6	82,1	66,1	81,0	73,5	80,3	65,4	80,6	72,3	81,9	<0,001
PTV																							
V95%(%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	>0,05
V100%(%)	94,79	95,89	98,10	97,29	97,19	96,69	96,80	96,18	96,08	96,08	98,60	96,29	98,10	94,70	96,69	97,30	95,09	94,50	96,59	96,27	96,80	96,12	>0,05
Dmean(Gy)	76,70	76,88	77,32	77,41	76,81	76,76	76,81	76,83	77,00	77,18	76,80	77,25	76,97	76,82	76,22	77,09	76,08	75,93	76,29	77,48	76,70	76,97	>0,05
RECTUM																							
Dmean(Gy)	24,87	25,65	23,43	25,78	20,70	21,80	19,07	17,61	26,49	27,72	29,00	31,65	25,07	27,43	31,51	29,56	24,21	23,00	26,61	25,40	25,09	25,56	>0,05
V75Gy(%)	0,50	0,50	4,21	5,71	0,80	0,90	0,80	1,51	2,61	3,61	4,11	4,31	1,80	0,90	3,41	4,50	2,20	2,10	2,20	1,71	2,42	2,58	>0,05
V70Gy(%)	2,00	2,30	7,21	8,92	3,01	3,61	3,30	3,42	6,63	7,43	7,62	7,82	4,10	4,60	8,92	8,81	5,31	5,20	5,41	4,53	5,35	5,67	>0,05
V65Gy(%)	3,31	3,91	9,02	11,32	4,31	5,72	4,50	4,93	5,62	9,84	9,52	10,42	5,20	6,30	11,12	11,41	7,31	7,10	7,11	6,45	6,70	7,74	<0,05
V60Gy(%)	4,81	5,61	10,62	13,63	5,82	8,23	6,11	6,84	10,34	11,95	11,02	13,13	6,40	8,00	13,03	13,81	9,72	9,00	8,62	8,26	8,65	9,85	<0,05
V50Gy(%)	10,42	10,72	14,93	19,94	12,94	15,36	13,21	12,98	13,86	16,67	14,93	19,54	12,80	15,80	20,44	19,42	16,53	14,10	12,42	12,69	14,25	15,72	>0,05
V40Gy(%)	18,64	21,04	23,35	30,56	21,16	25,90	19,22	19,92	21,59	24,70	24,85	30,46	20,60	25,40	0,00	0,00	25,35	23,10	21,84	19,74	19,66	22,08	<0,05
BLADDER	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Dmean(Gy)	17,38	16,78	13,91	11,52	10,30	8,69	9,79	7,31	16,66	12,72	16,44	13,40	11,03	10,34	77,74	78,69	19,04	18,81	14,46	11,44	20,67	18,98	<0,05
V70Gy(%)	5,71	6,31	6,91	5,11	3,61	3,11	3,00	2,11	6,02	4,62	7,11	5,71	4,70	5,50	6,91	5,81	8,12	8,40	4,11	3,42	5,62	5,01	>0,05
V65Gy(%)	7,41	7,62	8,52	6,21	4,61	3,71	3,80	2,52	7,73	5,32	8,82	6,91	6,20	6,80	8,52	7,01	9,62	9,90	7,62	5,14	7,28	6,12	<0,05
V50Gy(%)	12,53	11,92	12,12	9,02	7,32	5,42	6,31	3,92	12,35	8,03	13,33	9,82	11,00	10,00	14,43	11,21	14,73	14,30	11,52	7,45	11,56	9,12	<0,001
V40Gy(%)	16,93	16,43	14,53	11,22	9,73	7,23	8,71	5,43	16,47	11,04	16,53	12,12	13,40	12,50	16,53	13,21	18,84	18,50	14,73	9,87	14,64	11,76	<0,001
R.FEMORAL HEAD																							
V50Gy(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-
V45Gy(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-
L.FEMORAL HEAD																							
V50Gy(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-
V45Gy(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-

*:CI for 95% relative dose.

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there is no superiority for prostate planning between VMAT and IMRT. But unlike other studies, there was clinical and statistical significance for conformity of dose distributions (Conformity for 95% relative dose in VMAT: 81,9% and in IMRT: 72,3% ($p<0,001$)). (Table 1) Moreover, VMAT had superiority to IMRT in low dose region (Fig.2).

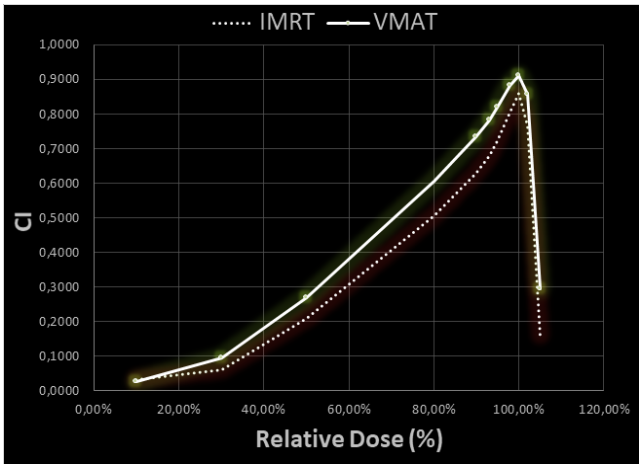

Figure 2. CI-Relative dose curves.

4. Discussion

Dosimetric comparison between IMRT and VMAT planning for prostate cases was studied by many researchers. Nguyen et.al. reported that according to IMRT (7 fixed beams), the VMAT (one arc) plans achieved better PTV dose conformity and OAR dose sparing with similar PTV coverage. But there was not clinical and statistical significance in results for PTV dose conformity (CI for VMAT: 0,964 and CI for IMRT: 0,958), bladder mean dose (26,29 Gy for VMAT and 27,29 for IMRT) and femoral head volumetric dose (V_{40Gy}=0 (%) for IMRT and VMAT). There was some statistical significance in rectum mean dose results despite no clinical significance (26,82 Gy for VMAT and 28,41 for IMRT) (Nguyen et al., 2019).

Another dosimetric comparison of VMAT (one arc) and IMRT (7 fixed beams) for prostate cancer was performed by Sale et. al, (Sale et. al, 2011). They reported that VMAT plans gives better results for OAR dose sparing (OAR including Rectum: V_{40Gy}=48,89 (%) for IMRT and V_{40Gy}=47,79 (%) for VMAT, V_{65Gy}=23,46 (%) for IMRT and V_{65Gy}=23,07 (%) for VMAT) (OAR including Bladder: V_{60Gy}=38,75 (%) for IMRT and V_{60Gy}=37,76 (%) for VMAT, V_{70Gy}=33,63 (%) for IMRT and V_{70Gy}=32,18 (%) for VMAT) with no clinical and statistical significance. Also results of mean CI were very similar (CI for VMAT: 0,81 and CI for IMRT: 0,80) (Sale & Moloney, 2011).

Onal et al. compared VMAT (one arc) plans and IMRT (7 fixed beams) plans where VMAT plans achieved lower doses in all OARs. They reported that VMAT plans were found to be dosimetrically equivalent to IMRT plans for prostate cancer patients with better rectum and bladder dose sparing. Also, for IMRT and VMAT, CI results of this study were 1,26 and 1,24, respectively (Onal et al., 2014).

According to results of a planning comparison in 10 patient datasets among 3-Dimensional Radiotherapy (3D-CRT), IMRT and VMAT reported by Palma et al, the lowest doses to the OARs were achieved in the VMAT plans (Palma et al., 2008).

A large study of 292 patient cases comparing VMAT and IMRT showed that VMAT could achieve lower mean doses to the bladder and rectum (Kopp 2011). In another planning study comparing the IMRT with the VMAT, similar results were seen in Hardcastle et. al., Ost et. al. studies (Hardcastle, 2011, Ost et al, 2011).

The results of conformity index calculations are more discrepant. While some studies reported improving conformity with VMAT, others reported better results with IMRT. This is because there are certain problems in currently used CI formulas. Some of existing CI formulas only take into account the irradiated healthy tissue volume, whereas others solely take into account the irradiated tumor volume (Gonultas, 2022).

There is some similarity between this study and other current studies in terms of DVH. However, unlike other studies, the results of our study clearly revealed the difference between IMRT and VMAT in terms of conformity. Because the new formula used in this study can help make a more realistic calculation for dose conformity.

5. Conclusions

The superiority of VMAT technique over IMRT technique has been clearly demonstrated thanks to ideal, novel and universal Conformity Index algorithm. When dose distributions were evaluated only with DVH results or existing CI formulas, clinically and statistically significant difference between plans was not clearly revealed in other similar studies due to the problems in currently used CI formulas. But novel equation used in the calculation of CI shows that there are clinically significant differences up to 16% between VMAT and IMRT. This leads to the conclusion that the new CI formula may be used as well as DVH for the selection of the best dose distributions.

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