Research Article

iMedPub Journals
www.imedpub.com

Journal of Medical Physics and Applied Sciences
ISSN 2574-285X

2022
Vol.7 No.1:001

VMAT and IMRT in Prostate Cancer: First Single Institutional Comparison in Pakistan

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Received: February 18, 2022, Manuscript No. IPIMP-22-11779; **Editor assigned:** February 21, 2022, PreQC No. IPIMP-22-11779 (PQ); **Reviewed:** March 07, 2022, QC No. IPIMP-22-11779; **Revised:** March 11, 2022, Manuscript No. IPIMP-22-11779 (R); **Published:** March 18, 2022, DOI: 10.36648/2574-285X.22.7.001

Citation: Baba A (2022) VMAT and IMRT in Prostate Cancer: First Single Institutional Comparison in Pakistan. J Med Phys Appl Sci Vol:7 No:1

Abstract

Prostate cancer is the second most frequently diagnosed cancer in men worldwide (Global Burden of Cancer Study, 2018). According to the American Cancer Society, in 2019, there were 1,74,650 affected cases and 31,620 mortalities. Estimation proposes that by 2040, new cases of prostate cancer will spike to 2,293,818. The occurrence and death rate of prostate cancer correlate with growing age, with an average age of approximately 66 years at the time of diagnosis.

With regard to the treatment of different cancers, various procedures are widely executed, but radiotherapy planning strategies are thought to be the most favorable. These techniques propose a high-portion target investigation without influencing the close structures, as their radiation resilience is low when compared with the essential portion for tumor control. In recent times, in addition to dimensional radiotherapy, dynamic techniques such as Intensity-Modulated Radiotherapy (IMRT) and Volumetric-Modulated Arc Therapy (VMAT) have been introduced.

Keywords: Volumetric-modulated arc therapy; Prostate cancer; Accelerator; Treatment

Introduction

IMRT and VMAT are progressively utilized in the treatment of different cancers, particularly prostate cancer [1-9]. The benefits of these two techniques are increasingly clearer as their usage strengthens, yet in complex cases, questions regarding the best setup emerge. Intensity-modulated radiotherapy is an advanced technique that uses linear accelerators to safely deliver precise radiation doses to a malignant tumor or specific area within the tumor, either by modulating or controlling the intensity of the radiation beams into different segments of various shapes [9-12]. Volumetric-modulated arc therapy is now a popular radiation technique and an advanced development of IMRT that delivers precise radiation beams for prostate cancer using a medical linear accelerator (Linac) equipped with a Multileaf Collimator (MLC) [13-21].

In VMAT, the gantry rotational dose, treatment aperture shape, dose rate, and collimator angle vary [22,23]. VMAT is advantageous over IMRT because of its smaller monitor units (MU) and shorter delivery time (2 min) [24-26]. Several research studies, particularly on prostate cancer, have shown that VMAT plans deliver better quality, good CP for target coverage (combined score), and improved OAR sparing compared to IMRT templates [15,27,28,17]. In addition to the frequently used IMRT techniques, dynamic rotational techniques, such as VMAT, are increasingly being introduced in the treatment of prostate cancer [14,29].

The purpose of this study is to compare and evaluate VMAT and IMRT treatment planning techniques to authenticate the advantage of one technique over another to treat prostate cancers in a developing country Pakistan as we see enormous number of prostate cancer patients [30].

Material and Methods

Data obtained from CT scans (3 mm slice thickness) of 55 prostate cancer patients, randomly selected at Shaukat Khanum Hospital, Lahore, Pakistan were analyzed for the present study. Organs at risk (OAR) include the urinary bladder and rectum. These patients underwent scanning with an empty rectum and a full urinary bladder. The simulations were run on Varian's CLINAC DHX having 6 MV and 15 MV photon energies. Patients were treated with 15 MV photon energies as 15 MV offers less hot spot and dose splash due to higher penetration power. For planning objectives, both IMRT and VMAT were optimised using an Analytical Anisotropic Algorithm (AAA) [31,32]. Two treatment plans were generated: one with 7-field IMRT plan with beam angles of 30°, 60°, 105°, 180°, 255°, 300°, and 330°, and the other with VMAT with two arcs. The prostate contour used for this study was the Clinical Target Volume (CTV), and by adding a 12 cm margin to the CTV in all dimensions of the Planning Target Volume (PTV) was generated. For all patients, the prescribed dose was 60 Gy delivered in 20 fractions (300 cGy per fraction). The dose constraints exercised were: 30% volume of bladder should not exceed more than 50 Gy of prescribed dose and 50% volume of bladder should not receive greater than 30 Gy of the prescribed dose. The same constraints were also set for the rectum.

Results and Discussions

Exposure to radiation: The constraints V50<30% and V30<50% were applied in the treatment planning algorithm, and the results are shown in Tables 1 and 2.

Table 1: Exposure of radiation to bladder for VMAT *vs* IMRT in constraint V50<30% and V30<50%.

VMAT			**IMRT**		
60 Gy; 300 cGy/fraction			**60 Gy; 300 cGy/fraction**		
Urinary Bladder			**Urinary Bladder**		
Patient	V50 Gy	V30 Gy	Patient	V50 Gy	V30 Gy
	<30%	<50%		<30%	<50%
1	28%	47%	1	33%	49%
2	17%	38%	2	22%	40%
3	20%	80%	3	25%	82%
4	22%	52%	4	34%	67%
5	41%	100%	5	46%	100%
6	15%	62%	6	20%	66%
7	25%	51%	7	29%	54%
8	35%	50%	8	39%	52%
9	22%	55%	9	25%	56%
10	16%	80%	10	20%	82%
11	22%	44%	11	25%	49%
12	17%	42%	12	29%	54%
13	25%	35%	13	29%	47%
14	15%	49%	14	26%	51%
15	22%	50%	15	28%	60%
16	18%	47%	16	23%	55%
17	20%	38%	17	27%	50%
18	24%	44%	18	29%	43%
19	18%	43%	19	23%	49%
20	17%	49%	20	29%	60%
21	18%	46%	21	27%	48%
22	25%	39%	22	30%	41%
23	24%	78%	23	30%	79%
24	15%	54%	24	26%	65%
25	17%	38%	25	23%	40%
26	16%	63%	26	20%	65%
27	23%	52%	27	25%	55%
28	17%	50%	28	28%	52%
29	26%	48%	29	28%	49%
30	16%	72%	30	21%	74%

31	23%	45%	31	27%	47%
32	15%	39%	32	21%	42%
33	27%	65%	33	32%	69%
34	18%	47%	34	23%	51%
35	21%	54%	35	25%	58%
36	22%	48%	36	25%	56%
37	39%	39%	37	46%	51%
38	14%	40%	38	20%	43%
39	25%	51%	39	27%	53%
40	34%	55%	40	39%	60%
41	22%	51%	41	26%	55%
42	16%	47%	42	21%	50%
43	25%	38%	43	23%	48%
44	21%	45%	44	27%	49%
45	24%	43%	45	28%	53%
46	19%	47%	46	24%	49%
47	18%	44%	47	20%	46%
48	20%	44%	48	27%	82%
49	18%	51%	49	30%	67%
50	23%	83%	50	30%	100%
51	25%	60%	51	26%	65%
52	15%	51%	52	22%	55%
53	20%	49%	53	28%	52%
54	22%	51%	54	27%	56%
55	18%	65%	55	20%	82%

Table 2: Exposure of radiation to rectum for VMAT *vs* IMRT in constraint V50<30% and V30<50%.

VMAT			**IMRT**		
60 Gy; 300 cGy/fraction			**60 Gy; 300 cGy/fraction**		
Rectum			**Rectum**		
Patient	V50 Gy	V30 Gy	Patient	V50 Gy	V30 Gy
	<30%	<50%		<30%	<50%
1	23%	49%	1	26%	50%
2	19%	41%	2	22%	42%
3	21%	79%	3	22%	82%
4	33%	78%	4	37%	81%
5	30%	89%	5	37%	90%
6	21%	67%	6	23%	69%

7	20%	49%	7	24%	51%
8	39%	81%	8	40%	82%
9	17%	49%	9	20%	51%
10	11%	71%	10	13%	74%
11	21%	46%	11	25%	49%
12	15%	51%	12	18%	53%
13	31%	47%	13	34%	51%
14	23%	44%	14	28%	49%
15	18%	47%	15	21%	51%
16	19%	53%	16	23%	56%
17	31%	51%	17	32%	57%
18	27%	46%	18	30%	51%
19	24%	44%	19	27%	50%
20	25%	53%	20	29%	55%
21	24%	48%	21	27%	50%
22	19%	43%	22	21%	46%
23	20%	77%	23	23%	82%
24	32%	71%	24	34%	74%
25	29%	87%	25	35%	90%
26	21%	57%	26	23%	68%
27	20%	48%	27	25%	52%
28	38%	81%	28	39%	84%
29	17%	49%	29	21%	52%
30	12%	73%	30	14%	76%
31	22%	47%	31	25%	49%
32	20%	52%	32	22%	54%
33	32%	46%	33	34%	51%
34	21%	45%	34	26%	49%
35	17%	50%	35	21%	51%
36	19%	54%	36	22%	57%
37	32%	52%	37	34%	56%
38	26%	45%	38	33%	52%
39	23%	44%	39	26%	49%
40	24%	53%	40	28%	55%
41	19%	46%	41	22%	49%
42	18%	54%	42	22%	60%
43	30%	56%	43	32%	57%
44	28%	45%	44	30%	49%
45	25%	44%	45	28%	50%

46	24%	51%	46	29%	54%
47	22%	43%	47	25%	47%
48	19%	41%	48	23%	44%
49	22%	78%	49	24%	82%
50	33%	76%	50	36%	80%
51	31%	87%	51	35%	90%
52	22%	65%	52	24%	68%
53	21%	48%	53	25%	51%
54	28%	80%	54	33%	82%
55	18%	42%	55	21%	49%

In VMAT and IMRT with the same dose delivered to the organs at risk, a lower percentage of bladder and rectum is exposed to high doses in VMAT compared with IMRT. For patient number 1, in the constraint 50 Gy<30%, in IMRT 33% volume of bladder and 26% volume of rectum is exposed to radiation, whereas in VMAT, only 28% of the bladder and 23% of the rectum are exposed. This shows that VMAT has 5% superior bladder sparing and 3% better rectum sparing for patient number 1. For patient no. 4, in IMRT, 34% of the bladder volume was exposed to radiation. However, in VMAT, only 22% of bladder volume was exposed. Here again, we see a 12% better bladder sparing in VMAT. Similar results were obtained for other patients. The percentage differences between VMAT and IMRT are given in Tables 3 and 4.

Table 3: Percentage difference of exposure to radiation between VMAT and IMRT for constraint V50 Gy<30% in Bladder.

Patient	Exposure to radiation in VMAT	Exposure to radiation in IMRT	Percentage difference b/w VMAT and IMRT
Urinary Bladder (V50 Gy<30%)			
1	28%	33%	5%
2	17%	22%	5%
3	20%	25%	5%
4	22%	34%	12%
5	41%	46%	5%
6	15%	20%	5%
7	25%	29%	4%
8	33%	39%	4%
9	22%	25%	3%
10	16%	20%	4%
12	22%	25%	3%
13	17%	29%	12%
14	25%	29%	4%
15	22%	28%	6%
16	18%	23%	5%
17	20%	27%	7%
18	24%	29%	5%
19	18%	23%	5%
20	17%	22%	5%

21	18%	27%	9%
22	25%	30%	5%
23	24%	30%	6%
24	15%	26%	11%
25	17%	23%	6%
26	16%	20%	4%
27	23%	25%	2%
28	17%	28%	11%
29	26%	28%	2%
30	16%	21%	5%
31	23%	27%	4%
32	15%	21%	6%
33	27%	32%	5%
34	18%	23%	5%
35	21%	25%	4%
36	22%	25%	3%
37	39%	46%	7%
38	14%	20%	7%
39	25%	27%	2%
40	34%	39%	5%
41	22%	26%	4%
42	16%	21%	5%
43	25%	23%	2%
44	21%	27%	6%
45	24%	28%	4%
46	19%	24%	5%
47	18%	20%	2%
48	20%	27%	7%
49	18%	30%	12%
50	23%	30%	7%
51	25%	26%	1%
52	15%	22%	7%
53	20%	28%	8%
54	22%	27%	5%
55	18%	20%	2%

Table 4: Percentage difference of exposure to radiation between VMAT and IMRT for constraint V50 Gy<30% in Rectum.

Patient	Exposure to radiation in VMAT	Exposure to radiation in IMRT	Percentage difference b/w VMAT and IMRT
Rectum (V50 Gy<30%)			
1	23%	26%	3%
2	19%	22%	3%
3	21%	22%	1%
4	33%	37%	4%
5	30%	37%	7%
6	21%	23%	2%
7	20%	24%	3%
8	39%	40%	1%
9	17%	20%	3%
10	11%	13%	2%
11	21%	25%	4%
12	15%	18%	3%
13	31%	34%	3%
14	23%	28%	5%
15	18%	21%	3%
16	19%	23%	4%
17	31%	32%	1%
18	27%	30%	3%
19	24%	27%	3%
20	25%	29%	4%
21	24%	27%	3%
22	19%	21%	2%
23	20%	23%	3%
24	32%	34%	2%
25	29%	35%	6%
26	21%	23%	2%
27	20%	25%	5%
28	38%	39%	1%
29	17%	21%	3%
30	12%	14%	2%
31	22%	25%	3%
32	20%	22%	2%
33	32%	34%	2%
34	21%	26%	5%
35	17%	21%	3%
36	19%	22%	3%
37	32%	34%	2%
38	26%	33%	7%

39	23%	26%	3%
40	24%	28%	4%
41	19%	22%	3%
42	18%	22%	4%
43	30%	32%	2%
44	28%	30%	2%
45	25%	28%	3%
46	24%	29%	5%
47	22%	25%	3%
48	19%	23%	4%
49	22%	24%	2%
50	33%	36%	3%
51	31%	35%	4%
52	22%	24%	2%
53	21%	25%	4%
54	28%	33%	5%
55	18%	21%	3%

In the constraint 30 Gy<50%, although more than 50% volume of OAR received 30 Gy, VMAT was comparatively better. Here, we should note that as 30 Gy is a low dose, it causes less toxicity, so it not does have much effect on OAR. In addition, Figures 1 and 2 depict the bar graphs showing the difference between exposure to radiation to the bladder and rectum, respectively. Hence, on average, the results show that in comparison to IMRT, VMAT showed 5.3% improved bladder sparing and 3% better sparing of the rectum.

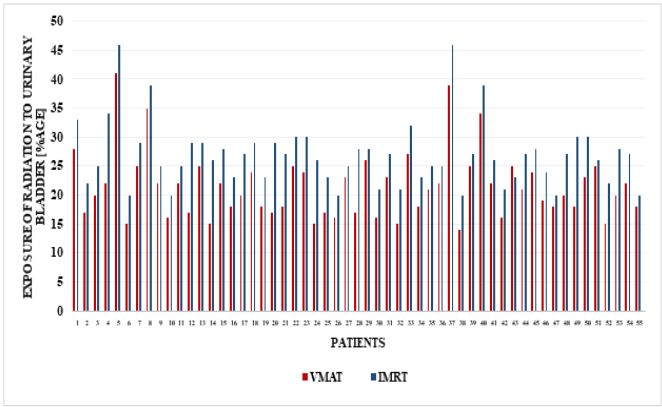

Figure 1: Exposure of radiation to urinary bladder in VMAT vs IMRT in constraint 50[Gy]<V30%.

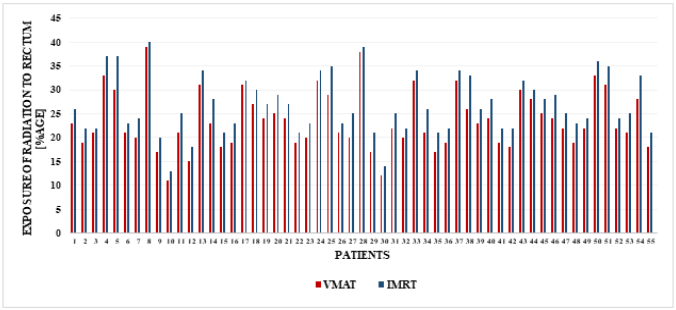

Figure 2: Exposure of radiation to Rectum in VMAT *vs* IMRT in constraint 50[Gy]<V30%.

Dose-Volume Histograms: The average Dose Volume Histograms (DVHs) of the rectum and bladder for the series of 55 patients, comparing IMRT and VMAT are shown in Figure 3 and Figure 4, respectively. For equivalent PTV coverage, VMAT plans in comparison to IMRT plans resulted in higher bladder and rectum sparing for doses >30 Gy. However, in the range, 0-30 Gy IMRT showed better OAR sparing than VMAT. Since a high dose causes more toxicity to the OAR, OAR sparing in low dose regions in VMAT is not alarming as the dose received is less (0-30 Gy). However, in IMRT plans, there is low OAR sparing for doses >30 Gy compared to VMAT. This indicates that in VMAT, a lower dose was delivered to the bladder and rectum for high dose regions, and an increased dose was delivered to the low-dose region. However, in IMRT, we see the opposite.

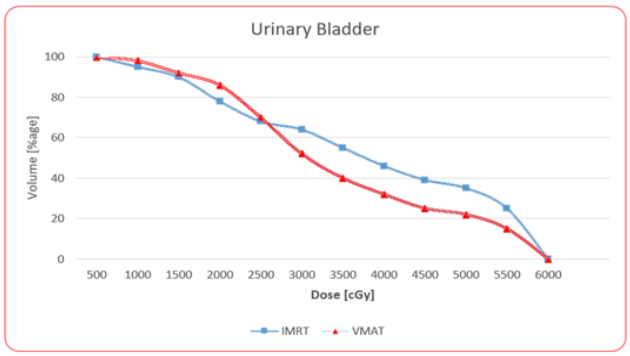

Figure 3: Average dose volume histogram of bladder.

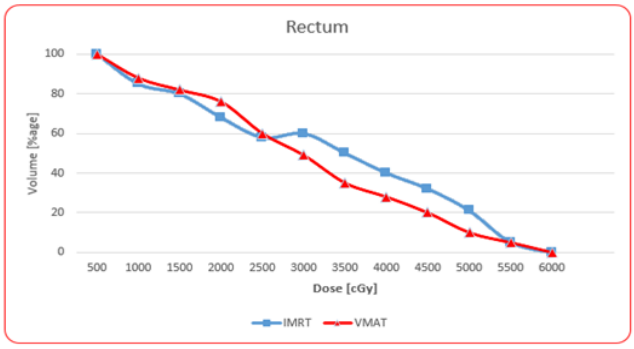

Figure 4: Average dose volume histogram of rectum.

Conclusion

The present study compared IMRT and VMAT in 55 patients with prostate cancer. To our knowledge, this is the first study to compare the above two radiotherapy techniques in Pakistan. The results showed a significant advantage of approximately 3% to 12% reduction in exposure to radiation of critical tissues in VMAT compared to IMRT for nearly all the constraints at high doses >50 Gy. On average, VMAT showed 5.3% improved bladder sparing and 3% better sparing of the rectum. In addition, the organs at risk sparing achieved by VMAT plans were better than IMRT for both rectal and bladder measured endpoints. Therefore, based on plan evaluation parameters, we infer that VMAT is superior and should be favoured over IMRT for the treatment of prostate cancer.

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