

Verifying the Supremacy of Volume Modulated Arc Therapy Over Intensity Modulated Radiation Therapy: Pelvis Malignancies' Perspective

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Abstract—Cancer, a leading fatal disease worldwide, can be treated with various techniques including radiation therapy. It involves the use of ionizing radiation to target cancer cells. On basis of source placement, radiation therapy is of two types i.e., Brachytherapy and External Beam Radiotherapy (EBRT). EBRT has evolved from 2-D conventional therapy to 3-D Conformal radiotherapy (3D-CRT) and then Intensity-Modulated Radiotherapy (IMRT). IMRT improves dose conformity and sparing of organs at risk. Volumetric Modulated Arc Therapy (VMAT) is a modern technique that uses treatment delivery in arcs with rotation of the gantry. In this report, a dosimetry comparison was performed between IMRT and VMAT. This study was conducted in the Radiotherapy Department of the Institute of Nuclear Medicine and Oncology Lahore (INMOL). Ten patients with Prostate Carcinoma were selected for this study to compare the methods. Simulation of these patients was done with help of a CT Simulator. All target volumes and organs were delineated by the oncologists. Then suitable fields/arcs were applied which cover volumes effectively. This was followed by the optimization of plans for both techniques for every patient. Finally, a comparison of evaluating parameters e.g., Conformity Index (CI), Volume Coverage, Homogeneity Index (HI), Organ Doses, and MUs (Monitor Units) was performed. We obtained better results of target conformity indices from VMAT (CI = 1.16) than IMRT (CI = 1.24). VMAT was better in organ sparing too. Also, VMAT shows fewer MUs (733 MUs) as compared to IMRT (2149 MUs). From this study, it is concluded that VMAT is a better treatment technique than IMRT. This technique will enhance treatment efficiency as it takes less time in obtaining the required results. Also, a very less scatter dose will be delivered to the patient.

Keywords—2-D Conventional Radiotherapy, 3-D Conformal Radiotherapy, Intensity Modulated Radiotherapy, Prostate Carcinoma, Radiotherapy, Volumetric Modulated Arc Therapy.

I. INTRODUCTION

UNARGUABLY, cancer is one of the most lethal diseases worldwide. The affected cells of the affected tissues exhibit uncontrolled division, forming visible masses. It has a pronounced mortality rate; according to International Agency for Research on Cancer (IARC), more than 180 million new cases of cancer were observed worldwide including 0.17 million cases in Pakistan in 2018. Cancer also adds to about nine million deaths worldwide including around 0.12 million in

Pakistan [1]. Cancer can be treated with numerous treatment techniques including Surgery, Chemotherapy, Radiotherapy, Immune therapy, etc. The patient is treated mostly with a combination of these modalities [2].

Radiotherapy is used generally for more than half of cancer patients' treatment stand-alone or combined with other methods. In Radiotherapy, ionizing radiations are utilized to target the cancer masses [3]. The fundamental aim of radiotherapy is to impart radiation doses in such a way that maximum interactions happen with tumor cells and make sure that healthy tissues and Organs at Risk (OARs) are saved. Radiotherapy is mainly divided into two main branches i.e., Brachytherapy and EBRT. In EBRT, radiations are delivered from an external source. Initially, Two-Dimensional Radiotherapy (2D-RT) was used for cancer treatment [4]. Bony landmarks were identified by Anterior-Posterior (AP-PA) and Lateral radiographs are taken in simulation. Rectangular fields were used to kill the volumes containing the tumor spread. This included many normal tissues in irradiated volumes. To spare these OARs, various shielding materials were used e.g., Wedges and Cerrobend molds [5].

Target volumes are obtained in three dimensions due to the involvement of the computed tomography (CT) scanning technique. Patients are accurately positioned and scanned as of treatment position. The resulting axial images are reconstructed to view in desired planes upon which the oncologist specifies and demarks the desired regions after contouring. The Medical Physicist can make a treatment plan by using 3-D CRT [6]. Dose conformity is obtained with the help of appropriate beams of "beam eye view (BEV)" on target images. Each beam has a unique gantry angle, weight, collimator angle, and shielding. Beam modification can be obtained by using different kinds of shielding blocks, wedges, and bolus materials [7]. Forward planning is used which accounts for tissue inhomogeneities present within the target volume. Multi-leaf Collimators (MLCs) are being used to shape the sub-segments which increases dose uniformity. After the advancement in MLCs and Inverse Planning Systems, IMRT was eventually developed. This technique is based usually on two main steps i.e., Dose optimization and Dose delivery [8]. Certain 'objective

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functions' are assigned to target tissues and organs. There are certain 'constraints' that must be satisfied at every cost. A better plan is considered the one that satisfies all these constraints and matches the objectives as good as possible with desired values. Multiple beams are used at specifically assigned gantry angles [9]. For every beam, optimized intensity levels are generated with Treatment Planning System (TPS). Every beam comprises numerous small beamlets that contain finely optimized levels of intensity. MLC controls and determines the width of these beamlets i.e., desired fluence map is obtained for every case [10].

The second step consists of the delivery of this fluence map by leaf sequencing of MLCs to form desired apertures. There are 02 delivery methods i.e., 'step and shoot' and 'dynamic' modes [11]. In the step and shoot method, at every gantry angle, first MLC leaves are arranged to obtain desired patterns and then the beam is switched on. All fluences are delivered one after another in this way. In dynamic mode, the beam is constantly turned on at a specific gantry angle. MLC leaves continuously move during this time and the desired fluence map is obtained for delivery [12].

To obtain better conformity, the IMRT technique elevates treatment time as many MUs are required to deliver its plans. Tomotherapy is a technique in which a dose is delivered slice by slice in a spiral way as a CT-scanner mechanism [13]. But again, treatment time and its setup are not efficient in many circumstances. The technique of VMAT was introduced with rotational of cone-beams [14]. The gantry delivers dose by continuously moving in an arc with the beam always on. This technique shows a considerable reduction in treatment time and MUs along with providing the same conformity and other benefits of IMRT. Delivery efficiency can be elevated by managing speed of gantry rotation carefully, controlling MLC leaves speed for the maximum amount of dose. VMAT can alter the dose rate during treatment delivery [15]. In optimizing the VMAT treatment plan, coarse sampling is applied at certain static gantry angles. Fluence maps or MLC aperture shapes are optimized at all these angles in the same way as in IMRT. A method of progressive sampling is used for this procedure. In this method, optimization is started using small samples and then adding new sample points. There should be enough number of samples available for the authentication of the dose models being used. For better delivery efficiency, the beam should be present throughout the arc rotation. However, some relaxations must be given due to limitations on gantry speeds and MLCs movements as well as variations in dose rates. MLCs are constantly varying positions as they did in the dynamic mode of IMRT [16]. There should be a certain time given to them to re-orient themselves before reaching the next sampling point. Less MUs and treatment time can benefit by delivering less scatter dose to the body of patients. This is also a key factor for the efficiency of the VMAT technique in clinical use [17].

In this study, IMRT and VMAT plans were compared for prostate carcinoma cases. MUs, CI, and HI were used as evaluating parameters. While comparing techniques, it was made sure that target coverage and doses to OARs were within

the limits suggested by International Commission on Radiation Units and Measurements (ICRU) [18].

II. MATERIALS AND METHODS

In this report, a dosimetry comparison was performed between the two latest techniques of radiotherapy i.e., IMRT and VMAT. This study was conducted in the Radiotherapy Department of the INMOL. Ten patients with Prostate Carcinoma were selected for this comparison. The Prostate cancer patients of stages 3 and 4 were chosen with diseases spread to the adjacent lymph nodes only (T3/T4N2M0). CT scanner was used to acquire initial simulation data of patients. This procedure is known as CT simulation [19]. For defining the treatment field reference point, LAP lasers were used. A slice thickness of 5 mm was used. Firstly, patients were positioned on CT scanner in the same position as of treatment position. Different gadgets used in treatment e.g., masks, pads, etc., were applied.

Radiopaque markers (fiducial) were used to set laser cross-sections [20]. Scout images were acquired for setting limits for the CT scans of the patient. CT scan of the transverse plane was acquired, and other planes were reconstructed with help of these data [21].

GTV-HR which contains the primary tumor was drawn in the pelvis region. CTV-HR was obtained by giving iso-central margins of 1.0 cm to GTV-HR. Nodal Volumes were delineated by the oncologist as CTV-LR. After giving 0.5 cm margins PTV-HR and PTV-LR were obtained. OARs like bladder, rectum, femoral heads, and small bowls were also drawn for each patient by the oncologist. Fig. 1 shows targets/OARs delineation in one of the prostate carcinoma cases. Doses to all targets/OARs were prescribed by the oncologist. PTV-HR was prescribed to give 70 Gy in 28 fractions. While in the same number of fractions, PTV-LR was prescribed 50.4 Gy. For the sparing of OARs, QUANTEC limits (2.5Gy/fraction) were followed. These limits were obtained by modification limits of 2Gy/fraction by calculating equivalent doses (EQD2).

For treatment planning, ECLIPSE TPS (Version 15.6.04) was used. It works on inverse treatment planning techniques. This system utilizes Photon Optimizer (PO) algorithm (version 15.6.04) for treatment plan optimization. After optimization, the dose is calculated by Anisotropic Analytical Algorithm (AAA) (version 15.6.04). TPS provides resultant dose-volume histograms (DVHs) of all targets and organs to evaluate the required parameters. 1.5 Arcs technique was used for the treatment of prostate cancer cases. The isocenter of these arcs was set upon the center of mass of PTV-HR. A suitable collimator angle was given to the gantry head to effectively cover all target volumes Fig. 2 demonstrates VMAT arcs upon the prostate area.

For IMRT of prostate carcinoma cases, 7 beams at equally spaced angles (50 degrees apart) were planned. The isocenter of these beams was set upon the center of mass of PTV-HR. IMRT planned beams are given in Fig. 3.

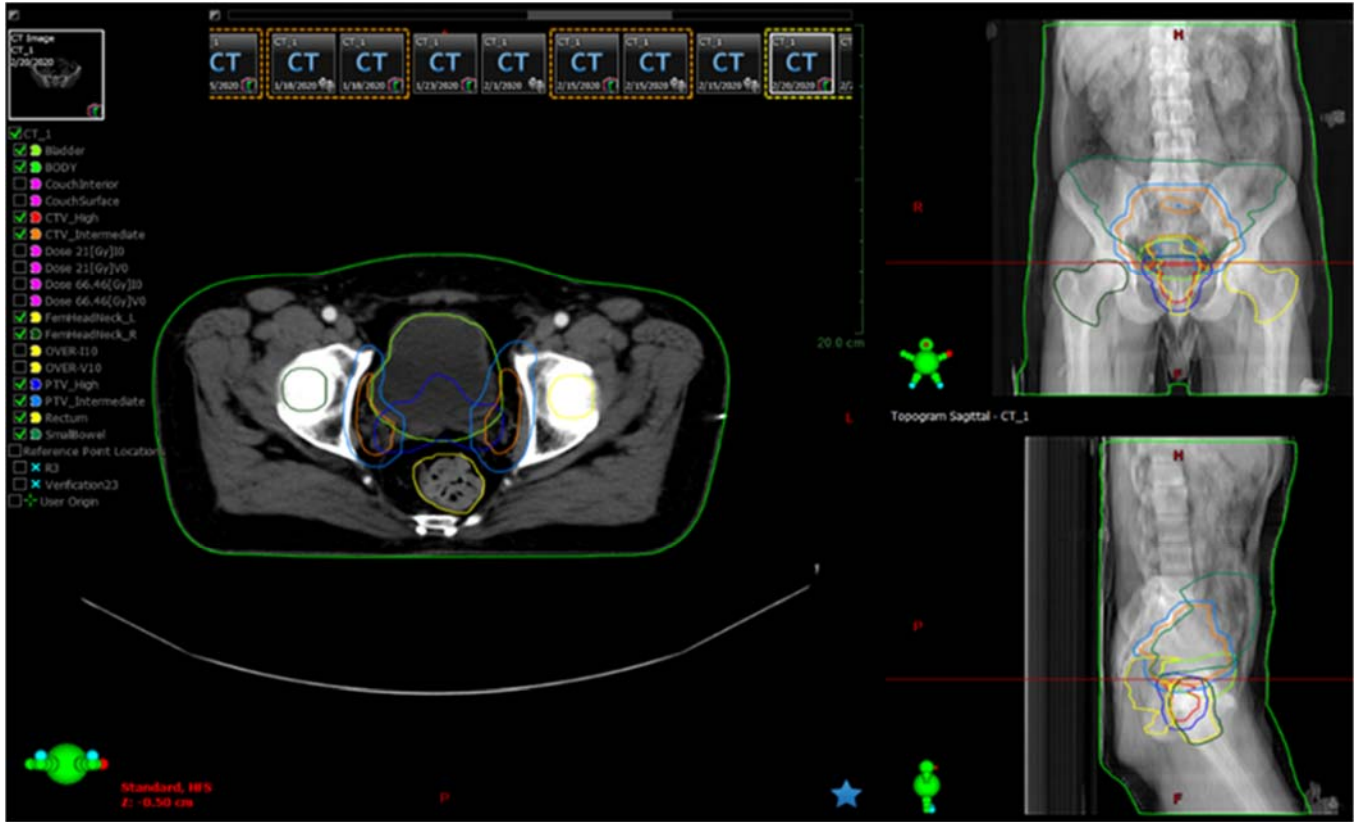


Fig. 1 Prostate Carcinoma case delineation

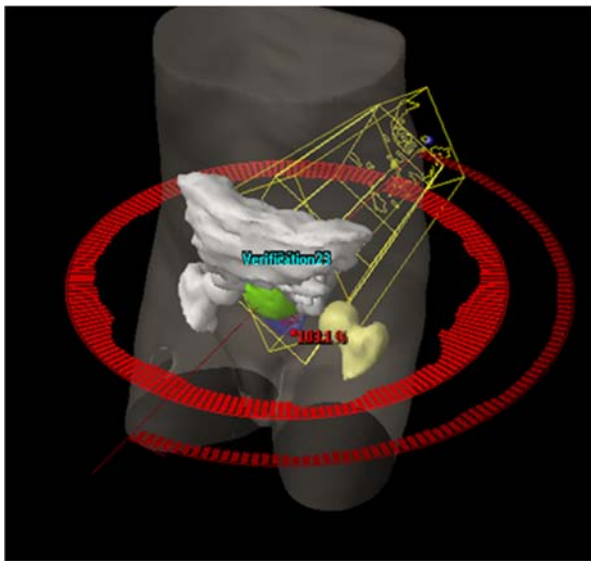


Fig. 2 Planned Arcs for VMAT Plan

For every case, a new treatment plan was created. First, the dose and number of fractions were set on our prescribed dose per fraction. Then arcs/beams were set for each case; the target coverage was observed for each arc/beam. Second, the optimization of the plan was started. In optimization, the first step was to specify maximum/minimum dose limits for targets (according to ICRU 50 [22]) and set constraints for OARs (according to QUANTEC limits) [22]. Afterward, priority

values were assigned to every demarked target/organ. Different iterations were performed to reach our desired goal. After completion of optimization, doses were calculated. Fig. 4 demonstrates the optimization window.

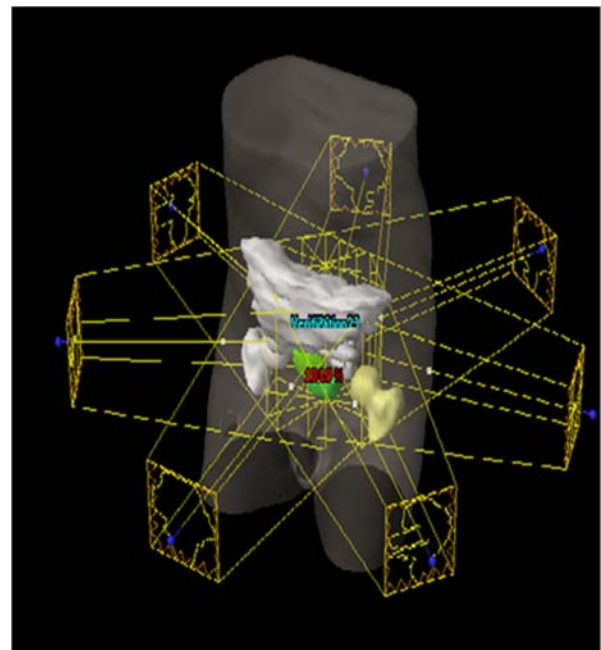


Fig. 3 Planned beams for IMRT Pla

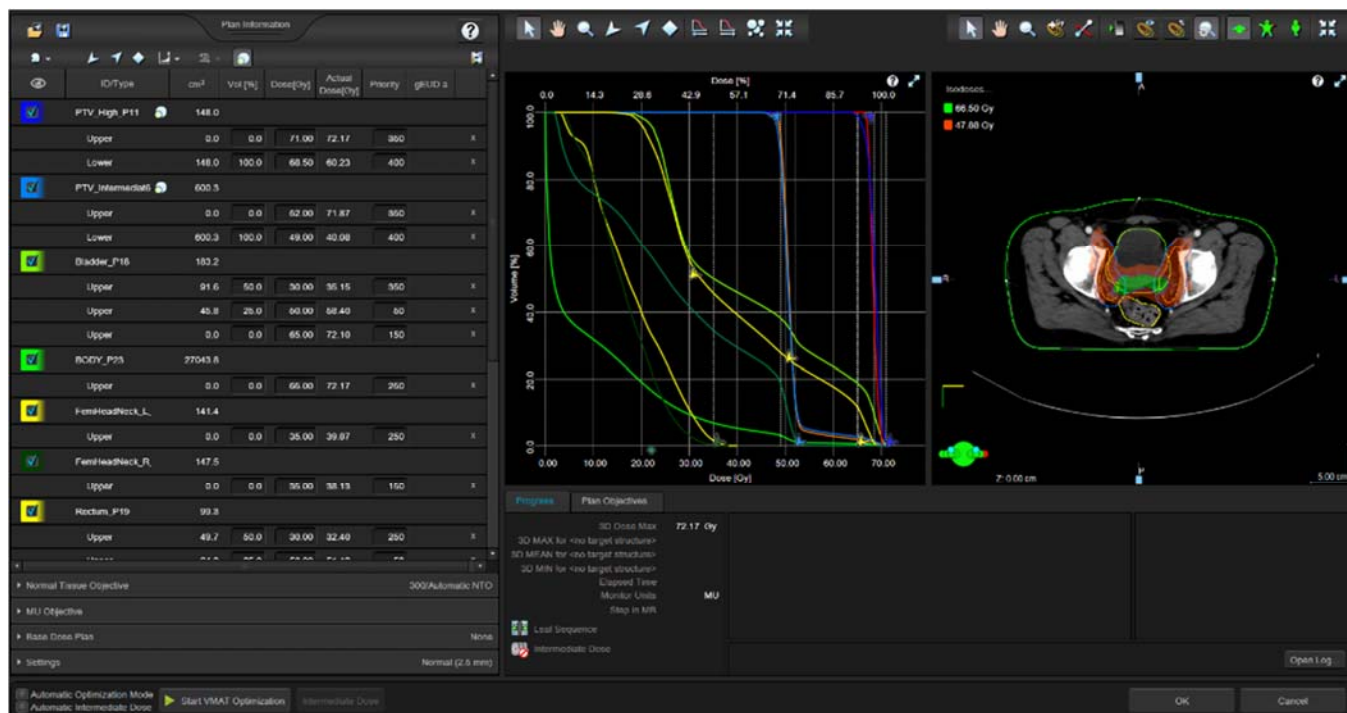


Fig. 4 Optimization Window of Eclipse TPS (Version 15.6.04)

Finally, all plans were evaluated on basis of the following evaluating parameters. In all plans, the same level of target volumes coverage was achieved which fulfills ICRU 50 criteria. By achieving this criterion, the impact on other parameters was assessed for both techniques. The CI was used for checking the conformity of dose coverage of PTV-HR Volume. Its formula as used in Lee et. al. [22] is given as:

$$CI = \frac{D_{95} \times V_{PTV}}{OV^2}$$

where D_{95} = Volume of 95% isodose curve; V_{PTV} = Volume of PTV-HR; OV = Volume overlapped between PTV-HR and 95% isodose curve.

The value of CI should be close to 1 for a plan having better conformity.

The HI accounts for homogeneity within the target volume. Its formula as given by Wu et al. [23] is given:

$$HI = \frac{D_2 - D_{98}}{D_p}$$

where D_2 = Maximum dose to 2% of PTV-HR volume; D_{98} = Maximum dose to 98% of PTV-HR volume; D_p = Prescribe dose to PTV-HR.

Ideally, its value should be close to 0 for better homogeneity. The tumor coverage factor (TCF) determines the coverage of a reference dose in PTVs volume. It is defined as:

$$TCF = \frac{\text{Volume of PTV receiving reference dose}}{\text{Total Volume of PTV}}$$

As properties of PTV-HR are well described by CI and HI,

we evaluated this parameter on other planning volumes. The reference dose here was 95% of the prescribed dose to respective volumes. It was made sure in every plan that doses do not go beyond limits assigned by QUANTEC. We noted every limit of every OAR and respective DVHs were also plotted. MUs for both plans were recorded and compared in each case [22]. This parameter has a direct relation with treatment delivery time and dose to the patient.

III. RESULTS AND DISCUSSION

The following results are obtained from work on prostate carcinoma.

A. Target Coverage

During optimization, it was made sure that plans of both techniques achieve the same level of PTV Coverage. So, all our plans achieved efficient coverage of target volumes. The average D_{95} for VMAT was 66.9 Gy and 66.5 Gy for IMRT. The average maximum dose in VMAT was 72.6 Gy and 73.6 Gy in IMRT. Fig. 5 shows the dose coverage of IMRT (a) and VMAT (b) of one of the cases of this study. The average CI value for VMAT plans was 1.16 and 1.24 for IMRT plans while average HI values were found 0.07 for VMAT and 0.06 for IMRT. These values show that both techniques show excellent results in these parameters.

VMAT shows slightly better value of CI than IMRT because it delivers dose from an arc instead of beams at some angles so better conformity of dose is achieved. On other hand, IMRT shows a slight improvement in HI as less conformity will give better homogeneity.

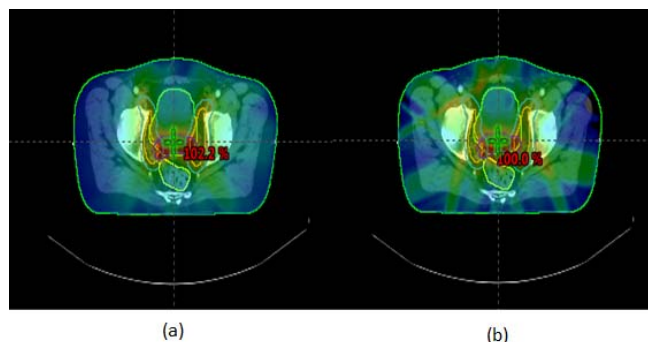


Fig. 5 Dose coverage of IMRT (a) and VMAT (b) in prostate carcinoma

The average TCF values for PTV-LR were 0.971 for VMAT and 0.947 for IMRT. It shows that both techniques exhibit excellent coverage of PTV low-risk volume. However, in comparison, VMAT shows a slightly better result. One possible reason for this is due to complete arc rotation and covering all volumes of PTV-LR effectively. Fig. 6 shows the average DVHs of all PTVs obtained in this study.

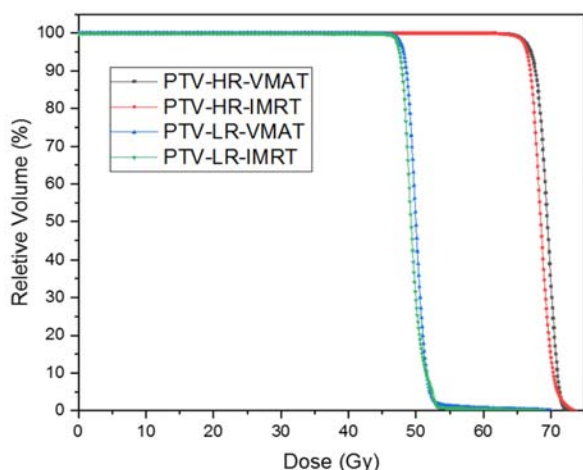


Fig. 6 Average DVHs of High-Risk and Low-Risk PTV

B. Doses to OARs

For the bladder, average values of QUANTEC limits (V59, V68, V72) were (20.93, 11.66, 0.24) for VMAT and (21.38, 8.09, 0.25) for IMRT. These values indicate that both techniques show excellent results as they are very much within limits. Although VMAT shows a slightly better bladder sparing as compared to IMRT. The reason for this sparing might be due to the presence of some IMRT beam which irradiates the bladder more compared to VMAT arc which will reduce its fluence if the bladder comes in its way. Rectum parameters of QUANTEC limits (V45, V59, V68) were (29.07, 12.26, 2.55) for VMAT and (31.84, 14.83, 2.02) for IMRT. Although both are within QUANTEC limits, VMAT demonstrates a slight superiority over IMRT in terms of rectum sparing. This is due to the complete arc rotation of VMAT as it will efficiently control its fluence when the rectum's volume will be in its way of radiating.

The average maximum dose to right femoral heads was 40.1

Gy and 39.77 Gy from VMAT and IMRT respectively. While to the left femoral heads, it was 40.5 Gy (VMAT) and 40.52 Gy (IMRT). These data depict that both techniques deliver doses that are within tolerance limits imposed by QUANTEC. However, IMRT delivers fewer doses in comparison with VMAT. One possible reason for this is that beams are angled at such points where they cover less volume of femoral heads so less dose will be delivered to them. The small bowel received an average mean dose of 25.79Gy from VMAT and 26.58Gy from IMRT. These values show that the results of both techniques are within limits. However, VMAT shows a slightly low mean dose than IMRT. The reason for this sparing is complete arc optimization. Fig. 7 shows the average DVHs of all OARs of prostate carcinoma obtained in this study.

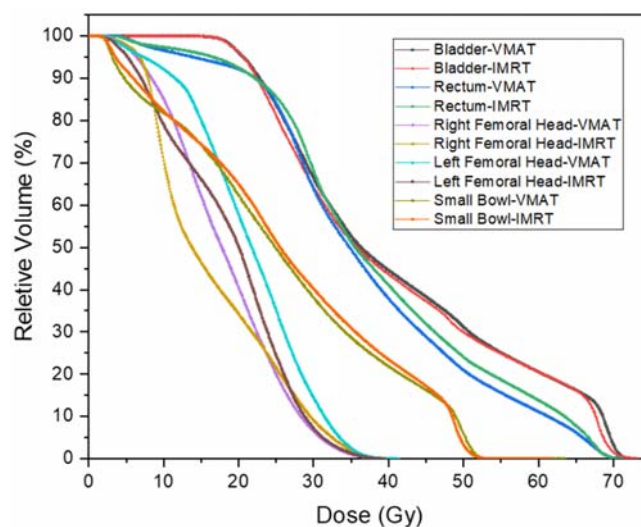


Fig. 7 Average DVHs of Femoral Heads, Rectum, Small Bowel, and Bladder

C. Monitor Units

Obtained average MUs for VMAT were 733.4 and 2149.1 for IMRT. This shows a huge difference between MUs that need to deliver to impose our plans. IMRT requires a larger number of MUs compared to VMAT which results in reduced overall treatment time keeping target coverage and OARs sparing the same.

IV. CONCLUSION

A dosimetric comparison was performed between Intensity Modulated Radiation Therapy and VMAT. After CT Simulation and targets delineation, suitable arcs/beams were used to generate treatment plans. It was concluded in this study that VMAT proves to be a better technique than IMRT. The optimization parameters i.e., CI, HI, and the number of MUs found to be improved in VMAT plans. For maintaining the same quality of plans, VMAT delivered fewer MUs which led to less treatment time and scatter dose. In developing countries like Pakistan, where the patient burden is one of the major concerns, VMAT will prove a more beneficial technique in treating many patients.

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