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ORIGINAL ARTICLE

The Effect of Varying Collimator Angles on VMAT planning of Prostate Cancer

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ABSTRACT

Background: The variation in collimator angles in the Volumetric Modulated Arc Therapy (VMAT) has been a factor of consideration in modern radiotherapy techniques for the treatment of cancer.
Aim: To investigate dose-volume evaluation in planning target volume (PTV) and organs-at-risk (OARs) in prostate carcinoma patients planned with 1.5 arcs for different collimator angles.
Methods: The collimator angle plays a vital role in VMAT planning due to leakage of radiation from the leaves of multi-leaf collimator (MLCs). Using the same optimization parameters on designated treatment planning system (TPS), the arcs of VMAT plans were optimized with 0°, 10°, 20°, 30°, 45°, and 90°, and 0°, 350°, 340°, 330°, 315° and 270° collimator angles. Different parameters like homogeneity index (HI), conformity index (CI), gradient index (GI), monitoring units (MUs), low dose coverage (V40Gy), maximum dose (Dmax), mean dose (Dmean), dose-volume histogram (DVH), D98%, D95%, etc. were calculated with Anisotropic Analytical Algorithm (AAA) Version 15.6.04 and results were analyzed.
Results: It was found that at 20°, 30° and 45° collimator angles, the dose conformity, homogeneity, and MUs have optimal values. The target coverage and dose to organ at risks at all angles is not significantly affected by different collimator angles.
Conclusion: According to this study it is advised to clinical medical physicists to make a solid decision about the collimator angles for treatment. The dosimetric analysis shows that the optimal collimator angle is necessary for different plan analyzing parameters like better conformity and homogeneity.
Keywords: Volumetric Modulated Arc Therapy. Prostate cancer, Planning Target Volume, organs-at-risk

INTRODUCTION

Cancer unarguably is one of the most lethal diseases worldwide. The cellsdoomed with carcinogenesis exhibit an uncontrolled division, forming visible masses known as tumors. 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]. It is a worldwide problem that impacts developed countries on a larger scale.There are many modalities used for treating and handling cancer. However, new treatment options for cancer are continuously being validated as over 60% of the present medical research worldwidefocuses on cancer treatment[2].

Radiation therapy was introduced after 1960 to treat cancer. The choice and progress of treatment depend on the type of cancer, its location, and the progression stage. Surgery, chemotherapy, and radiotherapy are some of the most commonly used conventional forms of treatment[3]. Radiotherapy is widely used worldwide for the treatment of cancer. It enlists different implementation techniques such as 3D-CRT, IMRT, and VMAT, which can be explained individually.In the treatment plan of three-dimension conformal radiation therapy (3D CRT), the uniform fluence of photons is delivered to the patients by the linear accelerator (LINAC) machines[4]. These ideas of the conformal dose distribution can be used on a large scale in the radiotherapy department before the Intensity-Modulated Radiation Therapy (IMRT) technique which includes clinical purposes such as decreasing the Normal Tissue Complication Probability (NTCP) and increasing the Tumor Control Probability (TCP)[5].

The main principle of the IMRT is to treat the patients with a large number of field directions in which the non-uniform fluence of the beam is delivered to the patients. IMRT is expected to be more efficient in target coverage, dosage homogeneity, and reduction of toxicity to OARs than 3-D CRT[6]. So, in this case, the dose is optimized for the target volume and the minimum or acceptable low dose is delivered to the organs at risk (OARs) or surrounding tissues. The field is divided into a large number of subfields (concerning gantry angles like 0°, 50°, 100°, 150°, 200°, 250°, etc.) by the treatment planning system and find out the best set of their intensity or field weight after optimization. For optimization techniques, we can use the inverse treatment planning in which the subfield (beamlet) weights or intensities can be defined to satisfy the prescribed dose criteria for a plan of composition[7]. The most advanced technique for the treatment of pelvis regions' tumors is the volumetric-modulated arc therapy (VMAT). VMAT is better than IMRT because it shots the target in arc i.e. 360 degrees are allowed to shoot the target, this gives better conformity, homogeneity, less treatment time, and small monitoring units (MUs)[8]. An evolution from 3D-CRT to VMAT (Fig. 1).

Figure 1: Evolution of Radiotherapy from 3D-CRT to VMAT

In VMAT, the gantry angle changes and beam is continuously switched on. During gantry rotation in the IMRT technique, the beam is switched off in-between the delivery of one beam and the next one[9]. The collimator angle is usually used in the VMAT plan and has importance in reduction of beam transmission (beam leakage) between the MLCs leaves. The transmission between multi-leaf collimator leaves accumulates at zero angle at the moment of the gantry rotation, and the accumulated leakage results in excessive dose distributions which cannot be controlled by optimization[10]. The unnecessary doses were managed at various collimator angles in the optimization process through dosage limits so that it decreases the unwanted dose[11].

The objective of this study is to find an optimal collimator angle that covers the planning target volume (PTV) and spares the OARs optimally for pelvis' treatment planning. The optimal

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collimator angle can be selected by checking the Conformity Index (CI), Homogeneity Index (HI), Gradient Index (GI), low dose coverage (V40), and monitoring units (MUs) etc. The finding of this analysis will help to guide the planner in selecting the right collimator angle[12]. In this study, the treatment planning was not changed, only the collimator angle was changed. The collimator angle can affect plan evaluation parameters of the VMAT plans for pelvis carcinoma patients.

MATERIALS AND METHOD

A total of ten patients were selected for the volumetric-modulated arc therapy (VMAT) planning of pelvis regions' cancers. Patient's images were acquired using CT simulator. Toshiba's Aquilian (16 slices) CT simulator was used for the CT simulation as shown in figure 2. Each patient was aligned individually using immobilization devices like knee-foot lock were used. Fiducial markers were used to present isocenteron CT images in treatment planning system (TPS) and on LINAC for patient positioning.

Figure 2: CT Simulator for image acquisition for VMAT

These CT images were transferred in DICOM format to the Eclipse (Version 15.6.04) TPS for contouring.The acquired images were contoured by radiation oncologists. Based on ICRU-50 protocol targets and OARs were contoured and segmented for treatment planning simulation. On each slice, the gross tumor volume (GTV) was delineated. Based on the ICRU-50 protocol, an extra margin of 0.5-1 cm was drawn around the gross tumor volume, which confined the target to form clinical target volume (CTV). For Planning Target Volume (PTV), margins were extended three-dimensionally from CTV, typically with margins limits ranging from 0.5-1 cm, based on the system of immobilization and respiratory coordination of patient. Dosecomparison was analyzed for different collimator angles i.e. 0, 10, 20, 30, 45, and 90 degrees. The VMAT plans were optimized individually for each collimator angle. There is only one variable in this project that is called the collimator angle while all the other parameters are constant. The prescribed dose was 70 Gy in 28 fractions. 1.5 full coplanar arcs was usedin treatment planning. For every arc, the field size was set according to the PTV. Plans were then optimized.

Plan optimization: VMAT plans were optimized on Eclipse's photon optimizer version 15.6.04. Upper and lower dose limits, volume constraints, and priority to different OARs and PTVs were imposed by the algorithm. Before optimization, these parameters were set according to the different organs upper, lower and mean dose limits according to RTOG guidelines for prostate cancer[1]. The upper and lower dose limits were set to 107 % and 95 % of the prescribed dose. Similarly, the volume constraints were set according to the acceptance criteria.

The dose coverage and uniformity depend on priority: The greater the priority, the more will be the dose conformity and uniformity. After the optimization of the VMAT plan for each patient, the doses were calculated. For the dose calculation, Anisotropic Analytical Algorithm (AAA) Version 15.6.04 with a grid size of 2.5 mm was used which also incorporated inhomogeneity corrections.

The variable dose rate method was used for the delivery of the prescribed dose 70 Gy to patients in 1.5 coplanar arcs. The first coplanar arc was angled from 179 to 181 degrees Counter Clock Wise (CCW) and the second coplanar arc was angled from 181 to 0 degrees Clock Wise(CW). The greater the number of arcs can provide better target coverage and conformity.

Dosimetric analysis: Treatment plans were analyzed by analyzing different parameters such as the dose homogeneity, conformity, gradient, monitoring units, low dose coverage (V40), $\boldsymbol{D_{98\%}}$, $\boldsymbol{D_{2\%}}$, $\boldsymbol{D_{50\%}}$, $\boldsymbol{D_{95\%}}$, $\boldsymbol{V_{50\%}}$, $\boldsymbol{V_{100\%}}$, and overlapping volume (O.V) for different collimator angles. Conformity is the measurement of how conformed the target volume is covered by the dose that is prescribed. Its optimal value is one. Equation 2.1 is another reported formula for the conformity index, which was used for the calculations of Conformity Index (C.I) in this study[13].

$$Conformity\ Index\ (C.I) = \frac{TV \times PTV}{(O.V)^2} \qquad 2.1$$

Where TV is the treated volume covered by 95% of the dose that is prescribed, PTV is the total volume of the target and O.V is the overlapping volume of the TV and PTV.

The homogeneity index (HI) is the measure of how the dose is distributed in the PTV. Its mathematical formula is given in equation 2.2[14].

$$Homogeneity\ Index\ (H.I) = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \qquad 2.2$$

Where $D_{2\%}$is the dosereceived by the 2% volume of the PTV, $D_{98\%}$ is the dose received by the 98% volume of the PTV and $D_{50\%}$ is the mean dose received by the 50% volume of the PTV. Its optimal value is zero. The gradient index (GI) is the measure of how the dose varies within the PTV[12]. Its mathematical formula is given in equation 2.3.

$$Gradient\ Index\ (G.I) = \frac{V_{50\%}}{V_{100\%}} \qquad 2.3$$

Where $V_{50\%}$ is the volume covered by 50% of the prescribed dose and $V_{100\%}$ is the volume covered by 100% of the prescribed dose. The lower gradient index shows better target coverage. All of the above formulas were used for the dosimetric analysis in this study.

RESULTS

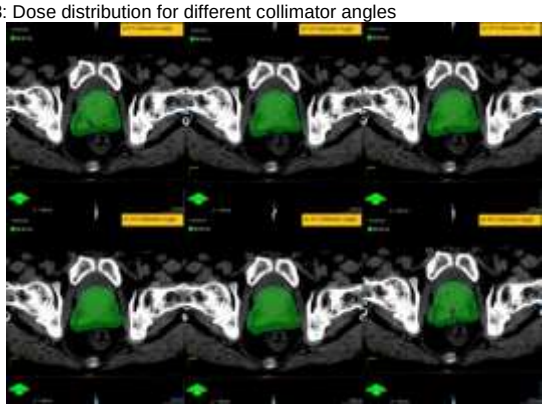
Different parameters like CI, HI, GI, MUs, etc. were calculated for each patient and were averaged for the same collimator angle. Table 1 shows the results of different parameters versus the collimator angles.

Table 1: The average dosimetric results for different angles of the collimator.

Collimator -Angles	0	10	20	30	45	90
C.I	1.19	1.18	1.17	1.17	1.16	1.21
H.I	0.079	0.071	0.069	0.070	0.066	0.077
G.I	43.23	50.27	38.58	54.18	60.72	38.89
MUs	1023.4	1022.8	934.2	921.8	996.8	1109
D_{max}(Gy)	73.55	73.52	73.51	73.33	73.32	73.90
V_{40}(cm^3)	311.92	309.44	298.96	296.46	299.16	309.02

It is evident that the conformity index, homogeneity index, D_{max}, MUs, andV_{40} (low dose coverage) first decreases and then increases for higher collimator angles. At 20°, 30° and 45° collimator angles, theseparameters have the smallest values which are important for good planning,and at 90° collimator angle, these parameters have the highest values. The dose coverage of the PTV was checked for various angles of the collimator as depicted in figure 3. The same slice was selected for evaluation from each collimator angle. From figure 3, it is observed that for 20°, 30° and 45° collimator angles, the target coverage is excellent whereas, at the other collimator angles, there are some cold spotsi.e. the target coverage is poor. Therefore, for the selection of optimal collimator angles, 30°, and 45° collimator angles is better for conformity.

Fig. 3: Dose distribution for different collimator angles



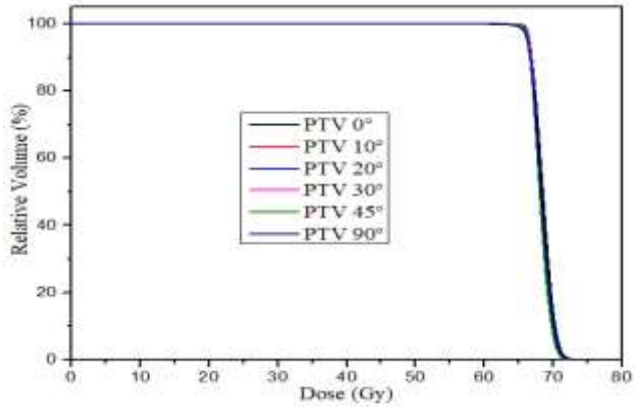
The OARs in prostate cancer are rectum, bladder, and femurs of both sides. The average values of mean dose, maximum dose, D50%, D35%, and D15% for bladder, rectum, and femurs at 6 multiple collimator angles for 10 patients is shown in Table 2. It reveals that there is no significant difference in different angles. From saving organs at risk in prostate cancer any angle can be the good candidate.

Table 2: The dosimetric results of patient for different collimator angles.

Collimator-Angles	0°	10°	20°	30°	45°	90°
Rectum						
Dmean (Gy)	31.98	31.34	30.98	30.6	30.74	30.56
Dmax (Gy)	73.76	71.67	72.54	72.79	72.82	72.74
D50% (Gy)	31.2	30.4	28.8	29.7	30.1	27.8
D35% (Gy)	39.3	37.4	37.6	37.6	36.4	36.2
D15% (Gy)	59.1	58.2	58.8	58.4	58.1	58.5
Bladder						
Dmean (Gy)	25.42	24.79	24.48	23.67	23.3	23.65
Dmax (Gy)	72.79	72.38	72	71.82	71.94	72.43
D50% (Gy)	19.5	17.7	18.5	15.4	14.2	14.1
D25% (Gy)	39.2	38.1	37.1	36.1	34.8	35.7
D15% (Gy)	53.3	52.2	50.8	50.6	49.7	50.2
L_Femur						
Dmax (Gy)	26.58	25.49	24.15	25.11	27.95	23.79
R_Femur						
Dmax (Gy)	29.32	23.51	25.46	28.1	31.74	27.51

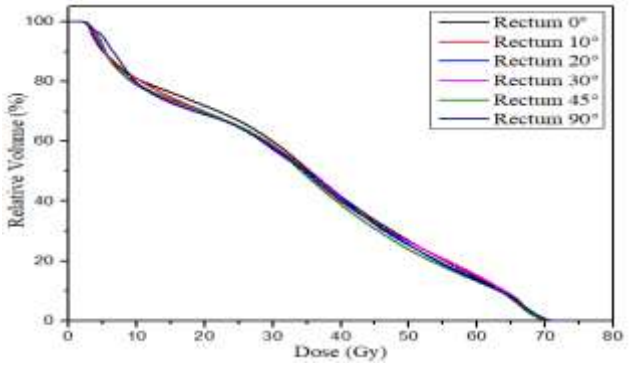
The average dose-volume histogram analysis of PTV and OARs for different angles of the collimator is shown in figures4 to 6. Figure 4 shows no significant difference in target coverage for different collimator angle. However DVHs shown here are not presenting micro details as it is presented in Figure 3 that target coverage for collimator angle 30^0 and 45^0 is better than other collimator angles.

Fig.4: The mean DVH of the Prostate PTV.



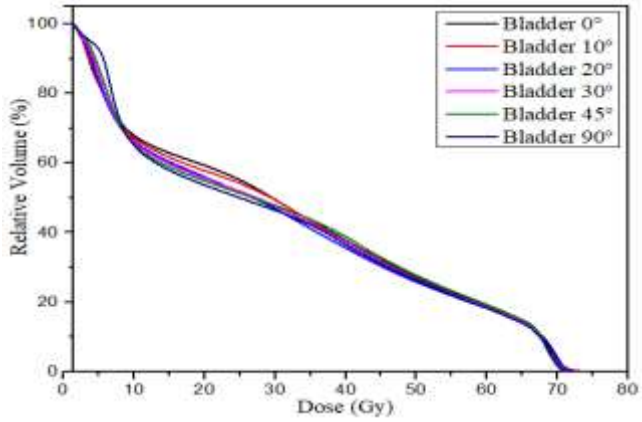
From figure 5, it is evident that for all collimator angles, the rectum doses were within limits. Rectum recommended dose limits for different volumes are V_{50Gy}< 50 %, V_{60Gy}< 35 %, V_{75Gy}< 15%.

Fig.5: The mean DVH of the Rectum.



From figure 6, it is evident that for all collimator angles, the bladder doses were within limit. Bladder doses limit are V_{65Gy}<50%, V_{75Gy}<25%, V_{80Gy}<15%.

Fig.6: The mean DVH of the Bladder.



DISCUSSIONS

The analysis of the above parameters shows that at 30^0 and 45^0collimator angle, the dose conformity and the dose homogeneity are best. Isa *et al*[4] suggested this in his paper that at a 45^0 collimator angle the dose conformity and the dose homogeneity are the best. At 30^0 collimator angle, the MUs, D_{max}, and V_{40} have the smallest values, which is important for good planning. At 30^0 angle, CI and HI are reasonable. At 90^0 collimator angle, the values of CI, HI, MUs, D_{max}, and V_{40} were larger which is not suitable for good planning.

From figure 3, it is observed that at 30^0 and 45^0 collimator angles, the target coverage is excellent while at the other collimator angles, the target coverage is poor, because of the cold spots in the target regions. From the DVHs of the target PTV and OARs, it can be observed that at every collimator angle, the target coverage and the sparing of the OARs is good. There is no such difference between the DVHs of different collimator angles. So the optimal collimator angle can be decided on basis of other parameters.

CONCLUSION

This research investigates the effect of various angles of the collimator on a dosimetric scoring feature. The choosing of the collimator angle may play a critical role in enhancing the efficiency

of treatment plans. It is inferred from the findings that there are major differences in the dosage with the variations in the collimator angle. Analyzing the results of the prostate cancer patients, it can be concluded that for prostate cancer patients, optimal collimator angle are 30° and 45°. At these collimator angles, the values of CI, HI, and MUs have the optimal values.

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