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Original Article

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Assessment of collimator angle variation in volumetric-modulated arc therapy planning for head and neck carcinoma patients

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Abstract

***Background & Aims*:** The collimator angle significantly impacts radiation leakage between the multi-leaf collimator (MLCs) leaves. This study aims to examine dose-volume evaluation in planning target volume (PTV) and organs at risk (OARs) for Head & Neck patients undergoing volumetric-modulated arc therapy (VMAT) with 2.5 arcs and varying collimator angles.

Materials & Methods: In this experimental study, five patients with nasopharyngeal cancer were selected for treatment with the VMAT method. CT images were prepared using a CT simulator and transferred to the treatment planning system. For optimizing VMAT plans, volume and dose constraints were applied to OARs and PTVs by the algorithm. Then, the doses were calculated using the AAA algorithm.

***Results*:** Although no significant differences were observed in DVH curves across different collimator angles, other parameters exhibited variations. Notably, in Head & Neck cancer patients, optimal values for dose conformity, homogeneity, MUs, and gradient index were found at collimator angles of 20° and 30°. Additionally, OAR sparing was favorable at these angles. Based on target coverage, homogeneity, and MUs, the collimator angles were optimized for VMAT planning.

***Conclusion*:** Our findings offer valuable guidance to clinical medical physicists in making informed decisions regarding collimator angles. The dosimetric analysis underscores the importance of selecting the optimal collimator angle for accurate PTV coverage.

***Keywords*:** Dose-Volume Histogram, Collimator Angle, Head and Neck Carcinoma, Planning Target Volume, Volumetric-Modulated Arc Therapy

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Introduction

Cancer is a worldwide problem that impacts developed countries on a large scale. There are various modalities of medical therapy used for treating and handling cancer. However, new therapeutic options for cancer are constantly being tested as over 60 % of the existing medical research globally concentrates on tumor treatment (1). Radiation therapy was introduced after 1960 to monitor local diseases. 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 used conventional forms of treatment. But radiotherapy is widely used worldwide for the treatment of cancer (2). It is different implementation techniques such as three-dimension conformal radiation therapy (3D CRT), Intensity-Modulated Arc Therapy (IMRT), and volumetric-modulated arc therapy (VMAT), which can be explained individually. The major challenge of treatment planning in radiotherapy is to impart highly conformal radiation doses to the planning target volume (PTV) while making sure the maximum safety of organs at risk (OARs). In the early 1990s, many approaches with modulated intensities for radiotherapy delivery were proposed (3), (4). The technique of VMAT provides efficient treatment delivery benefits over previously known techniques (2). The quality of VMAT dose distributions usually depends upon the selection of equipment, optimization algorithm for dose optimization, and user-dependent parameters (i.e., number of arcs, gantry and collimator rotation angles, delivery time, etc.) in general (5). In the treatment plan of 3D CRT, the uniform fluence of photons is delivered to the patients by the linear accelerator (LINAC) machine (6). These ideas of the conformal dose distribution can be used on a large scale in the radiotherapy department before the Intensity-Modulated Arc Therapy (IMRT) technique which includes clinical purposes such as decreasing the Normal Tissue Complication Probability (NTCP) and increasing the Tumor Control Probability (TCP) (7).

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 (8). 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.

The most advanced technique for the head & neck tumors is the volumetric-modulated arc therapy (VMAT). VMAT is one of the rotational techniques of IMRT (9). VMAT is better than IMRT because of less treatment time, the use of small monitoring units (MUs), and thus more efficient (10). In the VMAT plan, the gantry angle changes like in the static IMRT plan (during gantry rotation in the IMRT technique, the beam is switched off in-between the delivery of one beam to the next and the beam is switched on all the time in the VMAT plan during gantry rotation) and in this technique the dose rate and the collimator angles are also changed (11). The collimator angle is usually used in the VMAT plan and has great importance because it reduces the beam transmission (beam leakage) between the MLCs leaves (12). The transmission between multi-leaf collimator leaves accumulates at zero angles at the moment of the gantry rotation, and the accumulated leakage results in excessive dose distributions which cannot be controlled by optimization (13). The unnecessary doses were managed at various collimator angles in the optimization process through dosage limits so that it decreases the unwanted dose (14).

The objective of these studies is to find an optimal collimator angle that covers the planning target volume (PTV) and spares the OARs optimally for head & neck treatment planning and to find the shortcoming and strength of two different collimator rotations. The

optimal 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) (15). The finding of this analysis will help to guide the planner in selecting the right collimator angle (16). In this study, the treatment planning does not change but only the collimator angle can be changed. The collimator angle can affect dosimetric verification of the VMAT plans for head & neck cancer patients.

Materials & Methods

Patients' Selection:

A total of five patients were selected for the volumetric-modulated arc therapy (VMAT) planning from the Head & Neck region. In the present study, a total of five patients with nasopharyngeal cancer (NPC) were chosen for volumetric-modulated arc therapy. Patient's images were acquired using CT simulator.

CT Simulator:

Toshiba's Aquilian (16 slices) CT simulator was used for the CT simulation. Each patient was aligned individually using immobilization devices. Thermoplastic mask and headrest were used for patient immobilization. Fiducial markers were used to connect the CT machine with the treatment planning system (TPS) and LINAC during the entire treatment duration (17). These CT images were transferred in DICOM format to the Eclipse (Version 15.6.04) TPS for the contouring.

Delineation:

The acquired images were contoured by a trained radiation oncologist. Based on ICRU-50 protocol targets and OARs were contoured and segmented for treatment planning simulation (18). 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) (18). For 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 used.

Planning Procedure:

In this study, does comparison was analyzed for different collimator angles like 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 the collimator angle while all the other parameters are constant. The prescribed dose for nasopharynx patients was 69.96 Gy per 33 fractions (19). For treatment planning, 2.5 full coplanar arcs were used and for every arc, the field size was set according to the PTV. These plans were then optimized.

VMAT 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. The upper and lower dose limits were set to 107 % and 95 % of the prescribed dose (20). Similarly, the volume constraints were set according to the acceptance criteria. The dose coverage and uniformity depend on the priority. The greater the priority, the more will be the dose conformity and uniformity. After the optimization of the VMAT plan for each patient of nasopharynx, the doses were calculated (21). 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.

VMAT plan and treatment delivery:

The variable dose rate method was used for the delivery of the prescribed dose, 69.96 Gy for nasopharynx patients. The prescribed dose was delivered in 33 fractions, so that a dose of 2.12 Gy was delivered in a single fraction. The VMAT plans for patients' treatment consisted of 2.5 coplanar arcs. The first full coplanar arc was angled (gantry angle) from 179 to 181 degrees counterclockwise (CCW), the

second full coplanar arc was angled from 181 to 179 degrees clockwise (CW), and the half-coplanar arc was angled from 179 to 0 degrees CCW. The greater the number of arcs the better the target coverage and conformity.

Dosimetric Analysis:

The doses were analyzed by using the following parameters such as the dose homogeneity, conformity, gradient, monitoring units, low dose coverage (V40), $D_{98\%}$, $D_{2\%}$, $D_{50\%}$, $D_{95\%}$, $V_{50\%}$, $V_{100\%}$, and overlapping volume (O.V.) for different collimator angles.

Conformity Index (CI):

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 in this study (9).

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

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.

Homogeneity Index:

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 (22).

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

Where $D_{2\%}$ is the dose received 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.

Gradient Index:

The gradient index (GI) is the measure of how the dose varies within the PTV (16). Its mathematical formula is given in equation 2.3.

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

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 angle.

Table 1: The average dosimetric results for different collimator angles

Collimator-Angles	0	10	20	30	45	90
C.I	1.34	1.33	1.31	1.32	1.61	2.40
H.I	0.084	0.083	0.081	0.081	0.124	0.191
G.I	15.46	16.41	15.64	17.10	16.82	15.28
Mus	796.6	777.8	721.2	749.2	931.8	367.6
Dmax(Gy)	76.68	76.51	76.08	76.31	85.27	83.05
V40(cm3)	2182.52	2072.58	2023.98	2111.38	2280.24	2713.36

From Table 1, it is evident that the conformity index, homogeneity index, D_{max}, and V_{40} (low dose coverage) first decreases and then increases for higher collimator angles. At 20° and 30° collimator angles, these parameters have the smallest values which are important for good planning, and at 90° collimator angle, these parameters have the highest values. Mus also follow the same trend but at 90° collimator angle, it was the smallest and this is because of the poor target coverage and inhomogeneity of dose. The gradient index was not so important in this regime.

Dose Coverage for different Collimator Angles:

The dose coverage for different collimator angles can be checked by the following figure 1. Same slice was selected for evaluation from each collimator angle i.e., slice number having z value of - 4.5 cm. From figure 1, it is evident that at 45° and 90° collimator angles, the PTV coverage was poor. But for the other four collimator angles, the target coverage was good. But it doesn't mean that the other four angles were suitable for planning. For the selection of a good collimator angle, other parameters must also be evaluated.

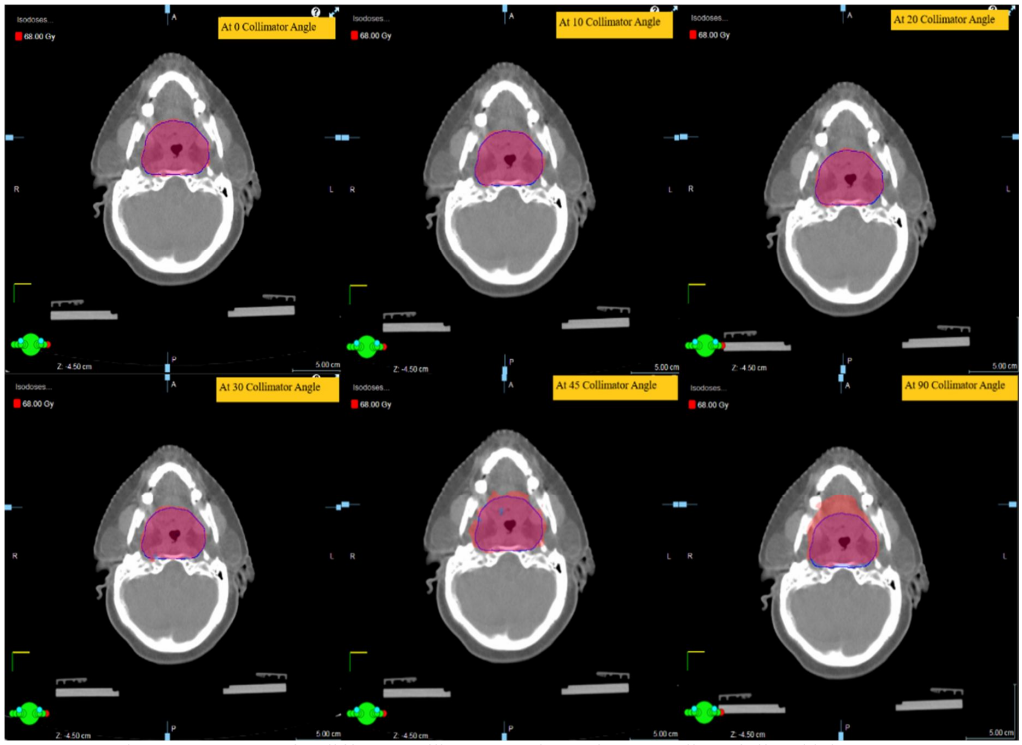

Fig. 1. The PTV coverage for different collimator angles at the same slice of slice thickness z=-4.50 cm

Dose-Volume Histogram:

The DVH evaluation of the PTV and OARs among various angles of the collimator are shown in figures 2 to 4. Figure 2, can show that at 45° and 90° collimator angles the coverage of the PTV is worst. But the other collimator angles the target coverage is best.

From figures 3 and 4, it is observed that at 45° and 90° collimator angles the OARs sparing was worse. But at the other collimator angles, the OARs can spare up to some extent. It is because of the PTV within small MLCs and dose were delivered among the small patches of the MLCs.

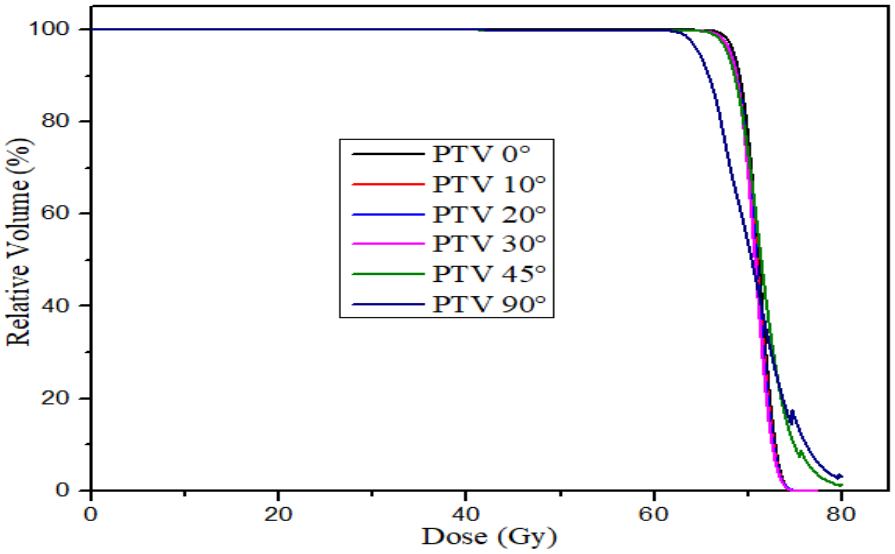

Fig. 2. The mean DVH of the PTV for nasopharynx.

From figure 3, it is observed that at 45° and 90° collimator angles the brain stem dose was beyond the limit, and for the other four angles, the brain stem dose was within the limit ($D_{2\%} < 55$ Gy).

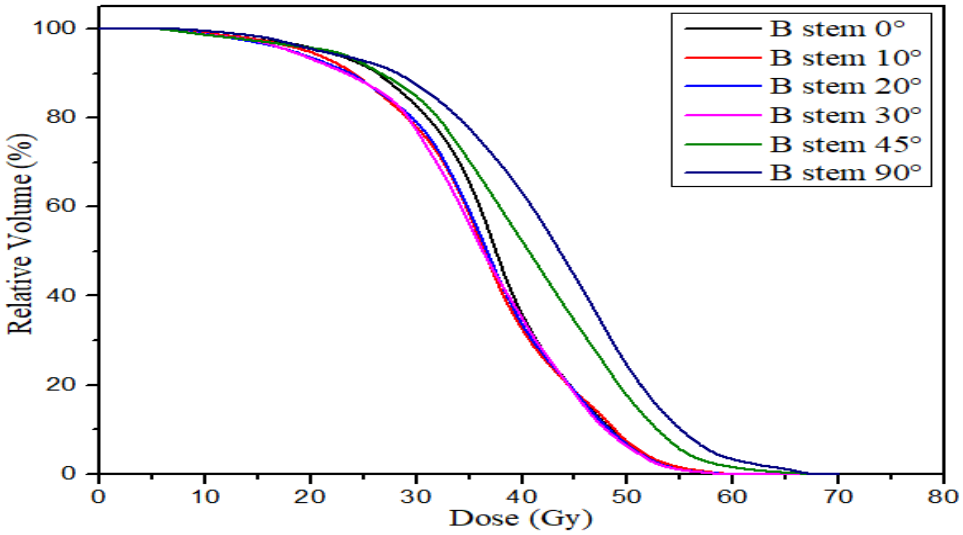

Fig. 3. The mean DVH of the Brain Stem

From figure 4, it is evident that that at 45° and 90° collimator angles the spinal cord dose was beyond the limit, and for the other four angles, the spinal cord dose was within the limit ($D_{2\%} < 45$ Gy).

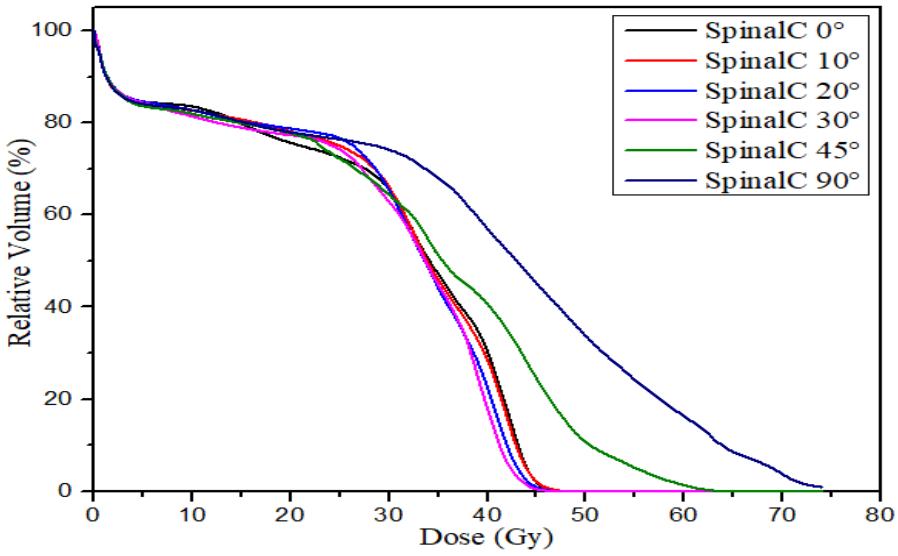

Fig. 3. The average dose-volume histogram of the Spinal Cord

Discussion

Comparing all of the above parameters in Table 1, it is evident that at 20° and 30° collimator angles, the dose conformity and homogeneity are best compared to other collimator angles. Also, the low dose coverage (V_{40}) and D_{max} values were good for 20° and 30° collimator angles. Yong Ho Kim *et al*. also indicated this in his paper that at 15° to 25° collimator angles the dose conformity and homogeneity are excellent. At 90° collimator angle, the monitoring units were lowest but, the dose conformity, homogeneity, low dose coverage, and maximum dose coverage were poor.

From figure 1, it can be observed that at 45° and 90° collimator angles the PTV coverage is poor. But at 20° and 30° angles of the collimator, the target PTV coverage is excellent. For other collimator angles, the target coverage is also good. This is in line with the findings of Serarslan et al., who found that all plans achieved adequate dose coverage for PTV (23). Similarly, Ahn et al. reported that the mean dose-volumetric parameters for target volume were comparable across different collimator angles (24).

The DVHs of the PTV and OARs reveals that at 45° and 90° collimator angles, neither the target coverage is good nor the sparing of the OARs. But for other collimator angles, the target coverage is good and the sparing of the OARs is also fine. There is no such difference between the DVH curves, it is because the results were averaged for five patients. This observation is consistent with the study by Serarslan et al., where they found that OARs are better protected when external beam radiotherapy is applied to the pelvis at a dose of 50.4 Gy by turning the collimator angle to 90° at some gantry angles 1. Bertholet et al. also found that dynamic trajectory radiotherapy could achieve substantial OAR sparing (25).

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 DVH curves because each curve is the mean of five patients. So the optimal collimator angle can be decided on the basis of other parameters. This conclusion aligns with the findings of Ahn et al., who found that for an irregularly shaped target, adjusting collimator angles reduced total MUs and improved sparing of normal organs (24). Similarly, Bertholet et al. found that dynamic trajectory radiotherapy provided a proof of principle for common head and neck cases with plans that were deliverable on a C-arm linac with high accuracy.

Conclusion

This research investigates the effect of various angles of the collimator on a dosimetric scoring feature. The choice 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.

Summarizing all of the above results of the nasopharynx cancer patients, it can be concluded that for head & neck cancer patients optimal collimator angle ranges from 20° to 30°. At these collimator angles, CI, HI, and MUs have the optimal values.

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Conflict of interest

The authors have no conflict of interest in this study.

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No declared.

Data Availability

The raw data supporting the conclusions of this article are available from the authors upon reasonable request.

Ethical Statement

This study was conducted with the highest regard for the dignity, privacy, and well being of the participants. All patients selected for the volumetric modulated arc therapy (VMAT) planning were fully informed about the nature of the study and the procedures involved. Informed consent was obtained from each participant prior to their inclusion in the study.

The patient's images acquired using the CT simulator were handled confidentially and in accordance with ethical standards for medical research. The use of immobilization devices, such as thermoplastic masks and headrests, was performed by trained professionals to ensure patient comfort and safety.

Patient data, including CT images transferred in DICOM format to the Eclipse Treatment Planning System, were anonymized to protect patient identity and were used solely for the purpose of this research.

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