ORIGINAL RESEARCH PAPER

Volume - 11 | Issue - 12 | December - 2022 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

DOSIMETRIC COMPARISON OF FLATTENING FILTER-FREE BEAMS WITH THE FLATTENED BEAM OF 6 MV AND 10 MV PHOTON FOR VOLUMETRIC MODULATED ARC THERAPY IN CERVIX CARCINOMA PLANS

Radiation Oncology

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ABSTRACT

Aim: To dosimetrically compare Volumetric modulated arc therapy (VMAT) plan of flattening filter-free beam (FFF) and flattened beam (FB) for 6 MV and 10 MV photon beams planned for cervix carcinoma cases. **Materials and Methods:** A total number of thirty three cervix carcinoma cases treated in 2021 and 2022 were selected retrospectively. The VMAT plans were prepared using Eclipse™ 13.6v Treatment Planning System. Prescription used for planning was 50 Gy in 25 Fraction. 16 patients planned with 6MV and 6MV-FFF beam. Remaining 17 patients were planned with 10MV and 10MV-FFF beam. Two full arcs with no avoidance sector were used in all plans. For inverse planning optimization Progressive Resolution Optimizer (PRO) with 2.5 mm grid size used and for dose calculation, Analytical Anisotropic Algorithm (AAA) was used. During optimization, dose objectives of PTV and OAR are kept constant between two plans. Priorities and NTO also maintained similar between two set of plans. Optimization and dose calculation steps are repeated sometimes to achieve clinically acceptable plan. The tools used to evaluate the plans are; Target Conformity Index (CI), Homogeneity Index (HI), dose to OARs, mean Normal tissue integral Dose (NTID), total monitor units (MUs) and Beam on Time (BOT) were analyzed. For statistical analysis, student t-test method was used. **Result:** From the results it is observed that plans created by FB and FFF beams are clinically acceptable. CI, HI in PTV coverage, normal tissue volume receiving low doses, MU and BOT are showing significant results. Mean NTID is found to be significant only in 10MV beams. FFF VMAT plans does not shows any significant dosimetric differences over FB VMAT plans in terms of OAR mean dose in cervix carcinoma cases. However 10 MV-FB shows better rectum sparing than 10 MV-FFF. **Conclusion:** FB can be used for VMAT plans when conformity and homogeneity Index are concerned. FFF beams VMAT plan can be used for patient those who have chances of secondary malignancies since it reduces volume receiving low doses.

KEYWORDS

Flattening filter-free beam (FFF), Flattened beam (FB), Volumetric modulated arc therapy (VMAT), Normal tissue integral Dose (NTID), Low dose volumes.

INTRODUCTION

Traditionally for more than 50 years, The Flattening filter (FF) was considered an integral part of the treatment head of a medical linear accelerator (LINAC)(1). The use of FF is to create the uniform flattened beam in conformal radiation therapy, intensity modulated radiation therapy (IMRT), and volumetric modulated arc therapy (VMAT); on the other hand, it reduces the dose rate of the photon beam from the linear accelerator(2). In standard linacs, FF has mounted in-between the primary collimator mechanism and monitor chamber. This conical-shaped FF of high atomic number material shapes the forward-peaking spectrum of radiation. Although it flattens the MV photon beam at a certain depth, it became a significant source of gantry head scatter radiation in the process(3,4).

Moreover, the FF hardens and attenuates the photon beams, the removal of this will soften the beam and increase the dose rate(3). Use of the FFF beam should lead to improves dose calculation, decreased penumbra, and lower dose outside of the field edge(4). The exclusion of the flattening filter also reduces the number of neutron production and resultant exposures(5).

Materials and Methods:

Patient selection:

A total number of thirty three patients with cervix carcinoma were retrospectively selected from the institutional patient database. The prescribed dose for planning target volume (PTV) was kept constant as 50Gy in 25 fractions.

Target volume and organs at risk definition:

Radiation oncologists delineated Target Volume in axial CT slices of 3mm thickness as per the recommendations of International Commission on Radiation Units and Measurements Reports (ICRU) 50 and 62, (ICRU Report 50, 1993; ICRU Report 62, 1999)(6,7). OAR's like bladder, rectum, femoral heads and bowel were also delineated.

Dose Prescription:

The VMAT technique was prepared to irradiate the PTV to a dose of 50 Gy in 25 fractions. Planning objective was to deliver 100% prescription dose (PD) to 95% of PTV with no more than 2% of PTV volume receiving 107% of prescribed dose as recommended by ICRU Report 83(8) (ICRU Report 83, 2010). The OAR constrains were given according to RTOG guideline(9).

Radiation therapy planning:

The treatment planning was planned using Eclipse™ 13.6v Treatment Planning System (TPS) (Varian Medical Systems, Palo Alto, CA, USA). Two sets of plans were created, one with FB and another with FFF photon beam. Among thirty three patients, sixteen patients were planned with 6MV-FB and 6MV-FFF beam and remaining seventeen patients with 10MV-FB and 10MV-FFF beam of Varian TrueBeam Linear Accelerator equipped with 60 pairs of Multi Leaf Collimator (5mm width at isocenter in the center pairs and 10mm width at isocenter in the peripheral pairs). The Nominal Dose rate of 400MU/min in 6MV and 10MV FB, 1400MU/min for 6MV FFF and 2400MU/min for 10MV FFF was used.

For all VMAT plans, Arc geometry of two full arcs with no avoidance sector was used. The Room Eye View (REV) of the arc geometry is shown in figure 1. Progressive Resolution Optimizer (PRO) with 2.5mm dose grid size was used for photon dose optimization. In the course of optimization, dose objectives of PTV and OAR are maintained identical between the two set plans. The optimization priorities and Normal Tissue Objective (NTO) were also kept alike between two set of plans. Anisotropic analytical algorithm (AAA) is used for photon dose calculation. Optimization and dose calculation steps are repeated sometimes to achieve clinically acceptable plan.

Plan Evaluation Methods:

The doses to PTV and OARs were analyzed from the cumulative dose volume histogram (cDVH), as recommended in ICRU report 83(8). Figure 2 and 3 represents the comparison of cDVH of the 6MV FB & FFF beam plan and 10MV FB & FFF beam plan respectively. Also, the color washes for the dose distribution of 95% over the PTV of both the

 PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

set of plans are shown in figure 4 and 5.

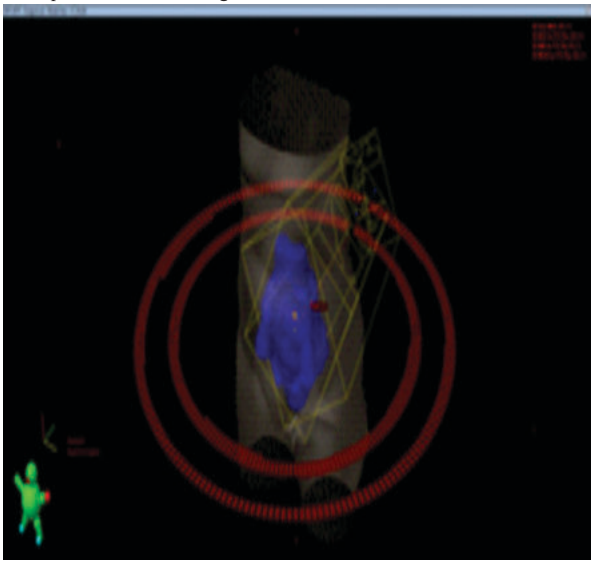


Figure 1: Room Eye View of VMAT plans with two full arcs with no avoidance

Homogeneity index (HI):
It is a tool to evaluate the homogeneity of the dose distribution over the PTV as suggested by ICRU 83(8) is given in equation 1.

$$\mathbf{HI} = \frac{(D_{2\%} - D_{98\%})}{D_{50\%}} \quad (1)$$

Where, $D_{2\%}$, $D_{98\%}$, and $D_{50\%}$ are the absolute dose delivered to 2%, 98%, and 50% volume of the PTV, respectively. HI of zero indicated homogeneous dose distribution.

Conformity index (CI):
Conformity index is a measure of degree of conformity of the absorbed dose distribution to the PTV. For the evaluation of CI, the paddick's Conformity index(10) was used.

$$\mathrm{pCI} = \frac{(\mathrm{TV}_{\mathrm{PIV}}^2)}{(\mathrm{TV} \times \mathrm{PIV})} \quad (2)$$

Where, TV_{PIV}, TV and PIV are the prescribed isodose volume over the target volume, Target volume and Prescription isodose volume respectively.

Normal tissue integral Dose (NTID):
NTID is seldom used in the clinical evaluation to radiotherapy plans. It is known that the risk of secondary malignancies increases with the increase in NTID(11). Integral dose describes the amount of energy deposited within the body. Hence the value of NTID is maintained as minimum as possible(12).

NTID is a measure of energy absorbed in non-target volume. it is calculated by the product of mean dose and the volume which is irradiated(13–17).

$$\mathrm{NTID} = V \times \rho \times \mathrm{Dmean} \quad (3)$$

Where, V, p and Dmean are the volume, density and mean dose of the volume respectively(11). Here, constant density value of $\rho = 1$ g/cc^3 was assumed for the minimalism for normal tissues.

For statistical analysis of the parameters used in this study was analyzed using student t-test method.

RESULT:
From the results it is observed that plans created by FB and FFF beams are clinically acceptable. CI, HI in PTV coverage, normal tissue volume receiving low doses, MU and BOT are showing significant results. Mean NTID is found to be significant only in 10MV beams. FFF VMAT plans does not shows any significant dosimetric differences over FB VMAT plans in terms of OAR mean dose in cervix carcinoma cases. However 10 MV-FB shows better rectum sparing than 10 MV-FFF.

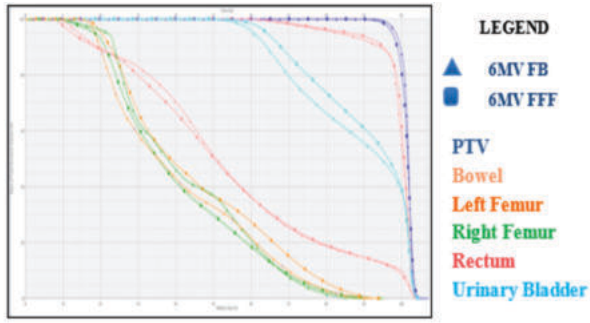


Figure 2: DVH comparison of 6 MV FB and 6 MV FFF beam plan

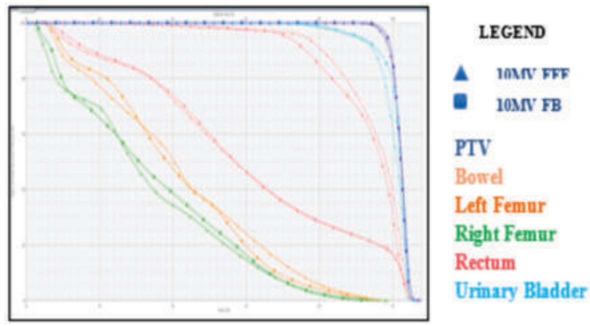


Figure 3: DVH comparison of 10 MV FB and 10 MV FFF beam plan

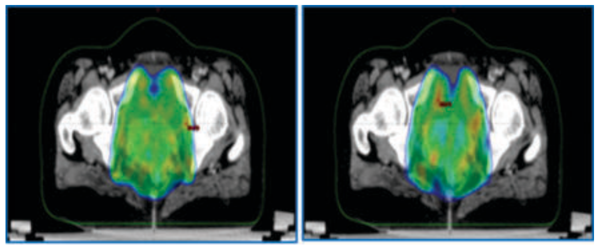


Figure 4: Dose coverage of 6 MV FB and 6 MV FFF

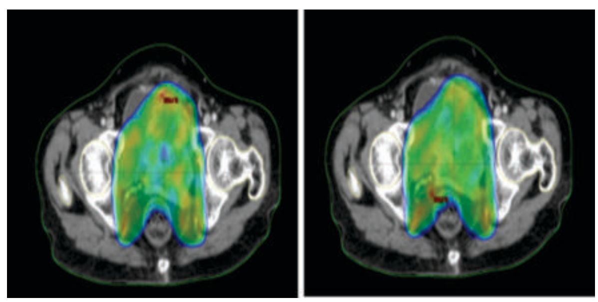


Figure 5: Dose coverage of 10 MV FB and 10 MV FFF

Table 1: Target Parameters Comparison between 6MV FB &FFF and 10MV FB &FFF for HI (Homogeneity index), CI (Conformity index), MU (Monitoring units) and BOT (Beam on time in minutes) *p values used in this table were analyzed using paired-student t-test method

Parameters	6MV FB VMAT		6MV FFF VMAT		10MV FB VMAT		10MV FFF VMAT		p value*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	6 MV	10 MV
HI	0.061	0.043	0.074	0.048	0.070	0.012	0.081	0.012	0.000	0.001
CI	0.868	0.043	0.842	0.0481	0.866	0.034	0.849	0.033	0.000	0.000
MU	495.81	23.373	533.94	45.496	456.00	35.034	601.06	67.177	0.000	0.008
BOT (in min)	0.826	0.039	0.381	0.032	0.760	0.058	0.250	0.028	0.000	0.000

 PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

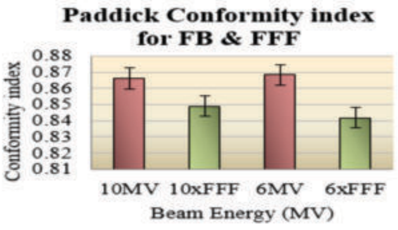


Figure 6: Paddick Conformity index for FB & FFF are plotted with the standard deviations.

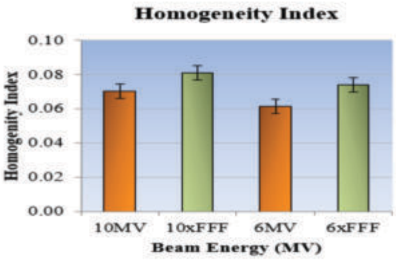


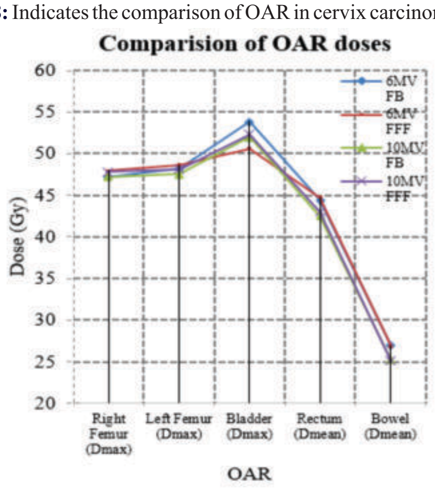
Figure 7: The bar diagram of homogeneity index of the sets of the plans were shown.

Table 2: OAR's Comparison between 6MV FB & FFF and 10MV FB & FFF

Parameters	6MV FB VMAT		6MV FFF VMAT		10MV FB VMAT		10MV FFF VMAT		p value	
	Mean (Gy)	SD	Mean (Gy)	SD	Mean (Gy)	SD	Mean (Gy)	SD	6 MV	10 MV
Right Femur (Dmax)	47.15	1.78	48.01	1.19	47.22	2.24	47.81	2.35	0.004	0.025
Left Femur (Dmax)	48.17	1.29	48.68	1.25	47.54	2.09	48.09	2.11	0.015	0.003
Bladder (Dmax)	53.86	7.45	50.63	6.92	51.99	1.01	52.31	0.63	0.176	0.075
Rectum (Dmean)	44.43	3.67	44.75	3.66	42.53	3.18	42.99	3.48	0.139	0.008
Bowel (Dmean)	26.96	4.33	26.86	4.70	25.24	7.87	25.11	7.84	0.513	0.077

Abbreviations: Dmean is mean dose and Dmax is the maximum dose; SD denotes standard deviation.

Figure 8: Indicates the comparison of OAR in cervix carcinoma cases.



DISCUSSION:

Few study which compares and comprehend the effect of FFF beams and its clinical aspects. The golden standard(18–20) of data for the radiation induced malignancies is low dose receiving volume of normal tissue increases the risk of secondary malignancies, the dose range up to 2.5Gy is consider to be as low doses. Also some studies(20–22) concluded that the most of the secondary cancer are near to the target volumes. Here, this study accounts the normal tissue receiving 1Gy, 2Gy 2.5Gy and 3Gy. These low dose volumes of normal tissues which excludes PTV are showing statistically significant and from Table 3, it is observed that FFF beam plans of both the energies have less low dose receiving normal tissues.

A comparative work of Nicolini *et al*.(23) on VMAT plan of FFF beam with IMRT and 3DCRT plans concluded that RapidArc plans with FFF beam have improved results in plan quality in advanced esophagus cases but the contrast results (Table 1) were observed while using FFF VMAT on complex and large target volumes. The graphical representations of CI and HI were shown in figure 4 and figure 5 respectively.

Table 3: NTID and low dose receiving Volume of sets of plans.

Parameters	6MV FB VMAT		6MV FFF VMAT		10MV FB VMAT		10MV FFF VMAT		p value	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	6 MV	10 MV
NTID	218.704	52.597	216.930	52.158	256.117	45.636	254.135	45.515	0.091	0.025
V_{1Gy}(cc)	13533.997	3907.163	13420.111	3954.878	16761.047	3322.928	16310.364	3297.561	0.000	0.000
V_{2Gy}(cc)	11601.205	3293.203	11168.806	3227.263	14534.935	2921.469	14075.935	2844.587	0.000	0.000
$V_{2.5Gy}$(cc)	11041.561	3107.463	10623.791	3034.102	13939.839	2792.230	13458.507	2716.879	0.000	0.000
V_{3Gy}(cc)	10587.279	2961.850	10210.346	2896.375	13413.374	2697.297	12975.614	2616.821	0.000	0.000

Despite of that our results agrees with the study by Subramanian *et al* which stated that the FB VMAT plans have marginal superiority with FFF VMAT plan concerning the homogeneity and conformity over the target as observed in Table 1.

Yan Y *et al*(24)in 2016 performed a study aims to observe the difference in plans using FFF and FB beams on 15 patient samples in the site of head and neck, lung and prostate. This study reports, FFF beam has no significance over FB in target coverage of different sites. It may due to fewer samples. This contradicts with our results. They also observed enhanced dose sparing on most of the OAR but for certain OARs FFF beam delivered greater maximum dose (Dmax). The similar observation was reported in Table 2, where both the femur receives higher maximum dose.

The study of Tamilarasu S *et al*(25) on evaluation of a 6MV FB and FFF beam for cervix cases by IMRT modality in 2018; from the work they concluded that FFF beam makes acceptable plans and it has the benefit of faster treatment delivery with lesser dose to normal tissues in IMRT. Similarly the clinical and dosimetrically acceptable plans were created by VMAT in FFF beams with different energies in our study. Also it has less beam-on time when compared with FB plans as shown in Table 1. Although FFF VMAT plan has an advantage of less beam on time, the MU was increased in FFF beams than FB beams which is co-relatable with the study(25). In their work 22% of MU increased in FFF IMRT was observed and here 8% and 32 % increase in MU were observed in FFF VMAT plans. It is obvious that more modulation over central axis is required due to forward peaking FFF beam profile to achieve homogeneity over PTV.

Çakır A *et al*(26) pursued a research on dosimetric influence of Flattening Filter (FF) and Flattening Filter Free (FFF) 6 and 10 MV photon beams on Volumetric Modulated Arc Therapy (VMAT) planning in case of prostate carcinoma. From the results they concluded that in prostate case, 10 MV FB and FFF plans reduced integral dose compared with 6 MV FB and FFF plans. High energy photons (10 MV FF, 10 MV FFF) have lower MUs than low energy photons (6 MV FF, 6 MV FFF). Multiple field radiation tends to decrease the volume receiving high radiation dose and increase the volume receiving low-dose radiation.

Guishan Fu *et al*(27) had done a study on FFF VMAT plan evaluation in 10 nasopharyngeal carcinoma cases. They came to the similar conclusion as in our study that the FFF beam prone to improve the normal tissue sparing while achieving similar target dose distribution. Decreasing of BOT in NPC cases was valuable in terms of patient's comfort.

M Zhuang *et al*(28) study aims to assess the role of FFF beams in VMAT for patients with 13 recurrent nasopharyngeal carcinoma. Their study additionally supports the results of ours; the dose distributions have good agreement with flattened beam arc plan. In addition to slightly faster delivery times, FFF produced better sparing of brainstem and normal tissue with uncompromised target coverage compared with flattened beam Rapid Arc plan. In our study, normal tissue sparing is significantly high in FFF VMAT plans.

A dosimetric analysis of FFFB and FB Photon Beam for Gastric Cancers Using IMRT and VMAT has been done by Manindra Bhushan *et al*(29) concluding that Unflatten beam spares the organs at risk significantly to avoid the chances of secondary malignancies reducing the intra-fraction motion during treatment. Inour research, we verify the integral dose to normal tissues and low dose receiving volumes which have an impact on secondary malignancies which also supports the above conclusion.

Kees H Spruijt *et al*(30) in their study on FFF versus FB for breast irradiation. They recruited 10 left breast patient aims to investigate FFF role in large-field treatments. Alike previous studies, the author concluded that FFF produces the comparable plans as similar to FB plans with shorter treatment time which is similar to our results.

A study on advanced nasopharyngeal carcinoma with VMAT and the potential role of FFF beams was done by Mingzan Zhuang *et al*(31) in 2013 to investigate the dosimetric characteristics of VMAT with FFF beams with ten cases and evaluate the role of VMAT in the treatment of advanced nasopharyngeal carcinoma. In this all the treatment plans has met the planning objectives and the dose measurements showed good agreement with computed doses. Hence they came to the conclusion that. FB has a greater dosimetric superiority than FFF in terms of good target coverage and sparing of critical structures. Here, in our case the FB shows better conformity and homogeneity and high energy FB beam shows better rectum sparing.

Sumanta Manna *et al*(32) in their study on dosimetric impact of FFF over FF beam using VMAT for thirty brain neoplasms cases to assess the dosimetric impact of FFF beam compared with FF beam plans. The reduction in average low dose volume and mean dose were observed. Also, a significant reduction was observed in the integral dose to the whole body using the FFF beam. This is quite comparable to the results obtained in our study with large field cases. Using the FFF beam with VMAT we can achieve similar dose coverage to the PTV with homogeneous dose distribution and increased conformity to the target volume as compared to the FF beam but in the large volume cervix cases, the homogeneity and conformity was marginally decreased in FFF VMAT plans.

CONCLUSION:

Both FB VMAT and FFF VMAT plans produces equivalent and clinically acceptable plans. Hence in VMAT cervix cases, FB plans can be recommend when conformity and homogeneity Index are concerned; FFF beams VMAT plan can be used for patient those who have chances of secondary malignancies since it reduces volume receiving low doses. A significant reduce in mean normal tissue integral dose is observed in FFF VMAT plans.

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