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Comparison of VMAT Plan Parameters for Carcinoma Head-and-Neck Regions using Flattened and Flattening Filter-Free High Energy Photons

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ABSTRACT:

Head and Neck Cancer is one of the most common cancers in India. This study aims to compare dosimetric characteristics of flattening filter-free (FFF) and flattened beams in Volumetric Arc Therapy (VMAT) for head-and-neck cancer using Elekta Synergy Platform Linear Accelerator. Volumetric Modulated Arc Therapy (VMAT) plans were generated for 16 head and neck cancer patients. The prescribed dose is considered to be 59.4Gy in 33 fractions. In order to analyse the plans conformity index, homogeneity index, and organ-at-risk (OAR) dose and Mus have been taken as the prime factors. The results showed that FFF beams provided comparable target coverage and improved dose conformity and homogeneity compared to flattened beams and comparable dose to organ at risks with respect to FF beams plans. These findings suggest that FFF beams offer dosimetric advantages in VMAT plans for head-and-neck cancer, potentially enhancing treatment efficiency and patient outcomes.

Keywords: TPS, VMAT, DVH, OAR, Monitor Unit, Conformity Index, Homogeneity Index, Integral Dose

1. introduction

Head and neck cancers are a significant health concern in India, accounting for around 30% of all cancer cases in the country. India has one of the highest incidences of head and neck cancers globally, with oral cancer being particularly prevalent. Statistics show that around 77,000 new cases of head and neck cancers are diagnosed annually in India, with a high mortality rate due to late-stage diagnosis and limited access to healthcare facilities. The five-year survival rate for these cancers in India is considerably lower compared to developed countries, primarily due to delayed diagnosis and lack of early intervention. Head and neck cancer treatment typically involves a combination of surgery, radiation therapy, and chemotherapy. Common treatments include surgery to remove tumours and affected lymph nodes, followed by reconstructive procedures. Radiation therapy, either as external beam radiation or brachytherapy, targets cancer cells, often used alongside chemotherapy to enhance effectiveness. Chemotherapy involves drugs that kill or inhibit cancer cells, while targeted therapy and immunotherapy utilize drugs like monoclonal antibodies and checkpoint inhibitors to specifically attack cancer mechanisms or boost the immune response. Post-treatment rehabilitation, including speech, swallowing therapy, and nutritional support, is crucial for recovery and quality of life. Participation in clinical trials may also offer access to cutting-edge therapies. Regular follow-up care is essential for early detection of recurrence and management of treatment side effects.

Flattening filter radiotherapy is a conventional technique used in radiation therapy to ensure uniform dose distribution across the treatment field. By incorporating a flattening filter within the linear accelerator, the intensity of the radiation beam is evenly spread, allowing for consistent and precise targeting of tumours. This method has been fundamental in treating various types of cancer, as it minimizes the risk of overexposure to surrounding healthy tissues while effectively delivering the prescribed radiation dose to the tumour.

Flattening filter free (FFF) radiotherapy represents a significant advancement in cancer treatment, offering improved dose delivery and reduced treatment times. Unlike traditional radiotherapy, which uses a flattening filter to even out the intensity of the radiation beam, FFF radiotherapy eliminates this filter, resulting in a more intense central beam and a faster dose rate. This innovation not only enhances the precision and effectiveness of the treatment but also reduces the exposure to surrounding healthy tissues. Consequently, FFF radiotherapy is becoming an increasingly preferred method in modern oncology, promising better outcomes and a higher quality of life for patients.

Volumetric Modulated Arc Therapy (VMAT) is a cutting-edge technique in the field of radiation oncology that enhances the precision and efficiency of cancer treatments. Unlike traditional radiation therapy methods, VMAT delivers radiation in a continuous rotational arc around the patient, allowing for highly conformal dose distributions. This technique enables the modulation of the radiation beam's intensity and shape in real time, resulting in shorter treatment times and improved sparing of healthy tissues. The advanced delivery mechanism of VMAT not only optimizes the therapeutic ratio but also enhances patient comfort and outcomes, making it a valuable option in modern cancer care.

2. Materials and Methodology

This study is hospital-based study that was carried out on 16 head and neck cancer patients for External Beam Radiotherapy (EBRT) treated during 2023 and 2024.

2.1 Patient selection

16 patients treated for head and neck cancer with an FF photon beam on an Elekta medical linear accelerator with VMAT of different HNCs were selected for this study. All patients received a 59 .4 Gy in 33 fractions. The patients were treated with a 6-megavoltage (6MV) FF beam, and for comparison with the FFF beam,16 equivalent treatment plans were created for Elekta Configuration. Patient simulation is performed on a Siemens CT simulator with a 3-mm slice thickness. Contouring of target volumes and OARs was done by a radiation oncologist. Contoured structures were transferred to the MONACO treatment planning system for treatment planning. Flattened and FFF beam plans were quantitatively compared in terms of coverage of planning target volume (PTV), conformity index, homogeneity index, organ at risk (OAR) doses and monitor units (MU).

2.2 Treatment planning

LINAC photon beams with AGILITY head and MLC of 5mm (160 leaves) with 6MV FF and 6MVFFF and HD beams were used for treatment planning. The most accurate method for calculating dose distributions in treatment planning with the Mosaiq fully integrated treatment planning system allows the optimizer to use the maximum Dose Rate of 500 MU/min for energy 6MV FF and 1400 MU/min for 6MV FFF beams. 16 patients were planned using the VMAT (ELEKTA Medical Systems) technique in the Monaco 6.1.4 with Monte Carlo (MC) algorithm. The Prescribed dose was (59.4Gy / 33 Fraction). The limitations of normal tissue and PTV goals were maintained throughout all schemes. Normalization of dose adjusted at dosage 95% of PTV received 100% of the prescribed dose and to minimize the PTV volume receiving >110% of the dose. For the OARs, the maximum dose of Brainstem 54<Gy, Spinal cord<50Gy, Mandible<70Gy and the mean dose of Parotid <25Gy were received.

2.3 Monaco Treatment Planning System (TPS)

The Monaco Treatment Planning System is an advanced software platform designed for radiation therapy, enabling precise and personalized treatment plans for cancer patients. Using imaging techniques such as CT, MRI, and PET scans, Monaco allows for detailed visualization of the tumour and surrounding tissues. This enables craft treatment plans that maximize the dose delivered to the tumour while minimizing exposure to healthy tissues. The Monaco Treatment Planning System (TPS) excels at creating Volumetric Modulated Arc Therapy (VMAT) plans, a sophisticated form of radiation therapy that delivers precise doses of radiation to cancer patients. VMAT involves the continuous delivery of radiation as the treatment machine rotates around the patient, allowing for highly conformal dose distributions and efficient treatment delivery. Monaco TPS enhances VMAT planning with its advanced optimization algorithms, which precisely calculate the best possible angles and dose distributions. FF and FFF Plans were generated using the Monaco treatment planning system for 6MV (Elekta Medical Systems Pvt. Ltd). The maximum dose rate was set to for FF and for FFF. VMAT technique was used for planning. The optimization was performed inversely using the same plan parameters such as position of isocenter, beam angle, arc number and field size. Doses were calculated using Monte Carlo (MC) algorithm. All original VMAT plans used single full arc of 360° gantry rotation from -180° to 180° in the clockwise direction and with a couch angle of 0 degrees. To exclude the bias of treatment plan skills of different individuals, in the final results, all treatment plans were designed by the same person.

2.4 VMAT Technique

Volumetric arc therapy (VMAT) is an advanced form of intensity-modulated radiation therapy (IMRT) that enhances the precision and efficiency of cancer treatments. By delivering radiation in a continuous 360-degree rotation around the patient, VMAT allows for highly conformal dose distributions that closely match the shape of the tumour while minimizing exposure to surrounding healthy tissues. This technique utilizes dynamic multi-leaf collimators (MLCs) that adjust the beam shape in real-time, along with variable dose rates and gantry speeds, optimizing the radiation delivery. The result is a more effective treatment with shorter delivery times compared to traditional IMRT, improving patient comfort and throughput in clinical settings. VMAT is particularly beneficial for treating complex or irregularly shaped tumours, offering a significant advantage in the precision and adaptability of cancer radiotherapy.

In Monaco TPS Volumetric Modulated Arc Therapy (VMAT) Plan can optimize single or many noncoplanar arcs at the same time, allowing for greater flexibility and control in more complex treatment programs. Arc designs can be given with a single button push at the linear accelerator console, resulting in optimal treatment efficiency.

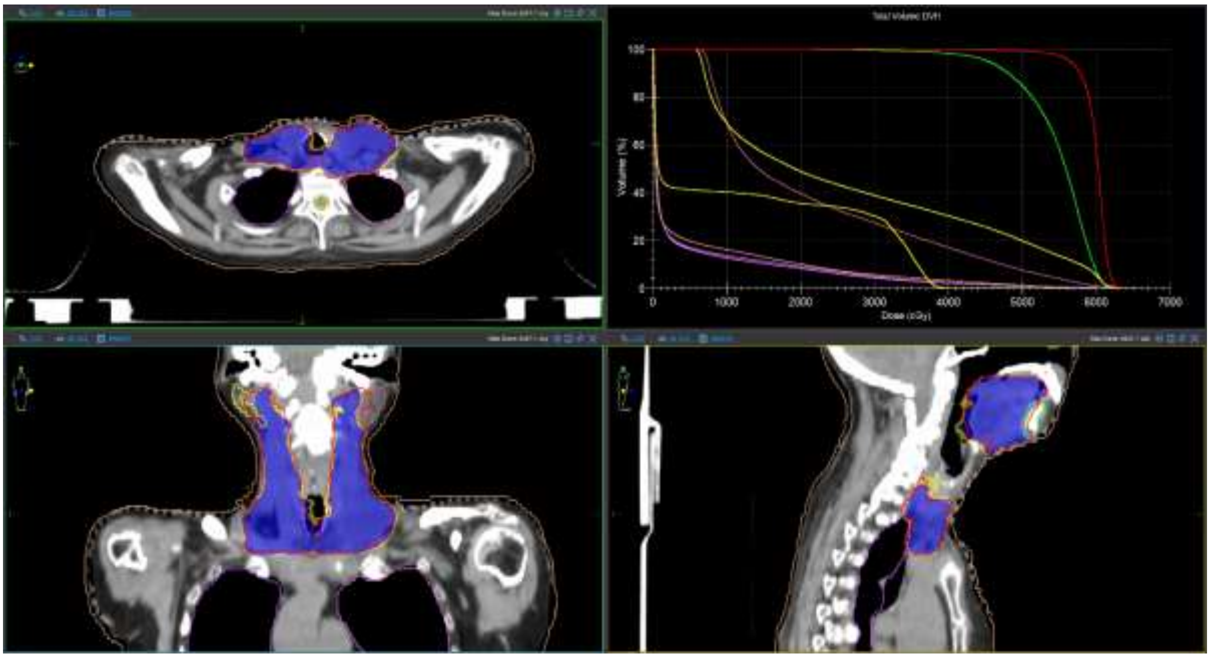

Figure 2.1: $V_{95\%}$ dose color wash of one of the VMAT case for 6MV FF

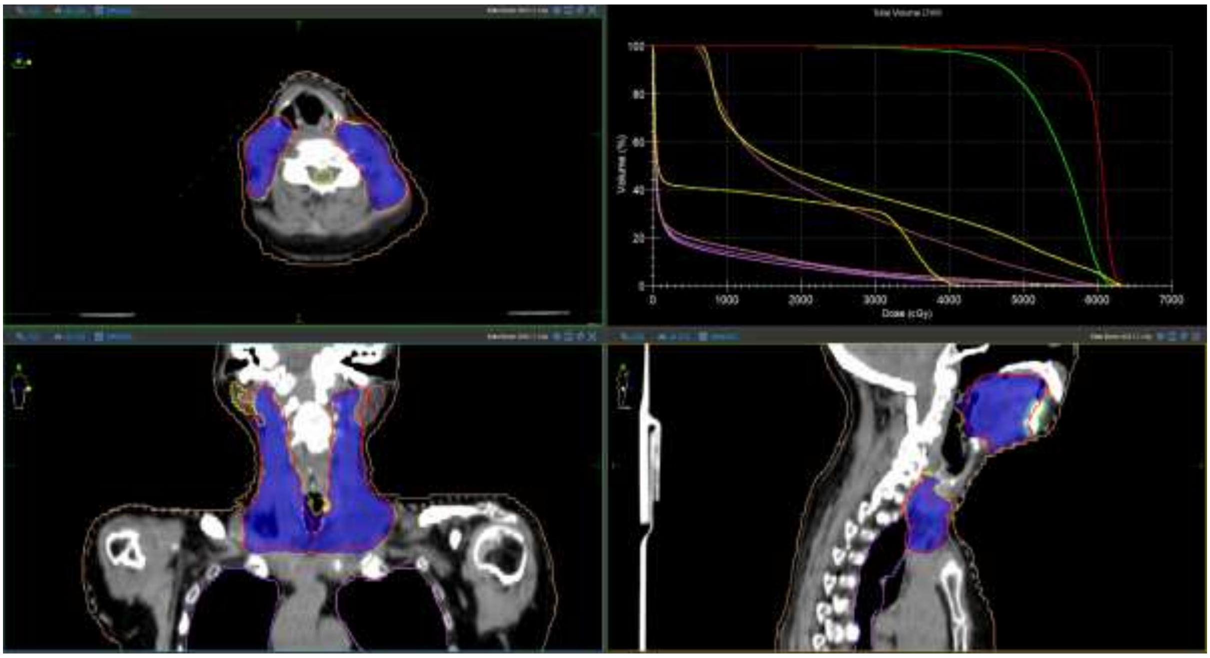

Figure 2.2: $V_{95\%}$ dose color wash of one of the VMAT case for 6MV FFF

2.5 Dosimetric evaluation

The Plans were optimized in the TPS, so as to ensure proper coverage of the PTV and sparing the organs at risk. The plans were evaluated such that at least the 95% of the prescribed dose to cover 95% of PTV Volume and that dose to PTV should not exceed 110% of the prescribed dose i.e., hotspot.

For each patient, PTV and volume of PTV getting 95%of the prescribed dose values are noted to calculate Conformity index, Homogeneity index, Integral Dose and Monitor Unit.

Dose volume histograms (DVHs) were generated for all involved structures, including the PTV, contralateral lung, heart and the untreated breast. OAR dose of the spinal cord, oesophagus, and parotids was also evaluated from Dose Volume Histogram (DVH).

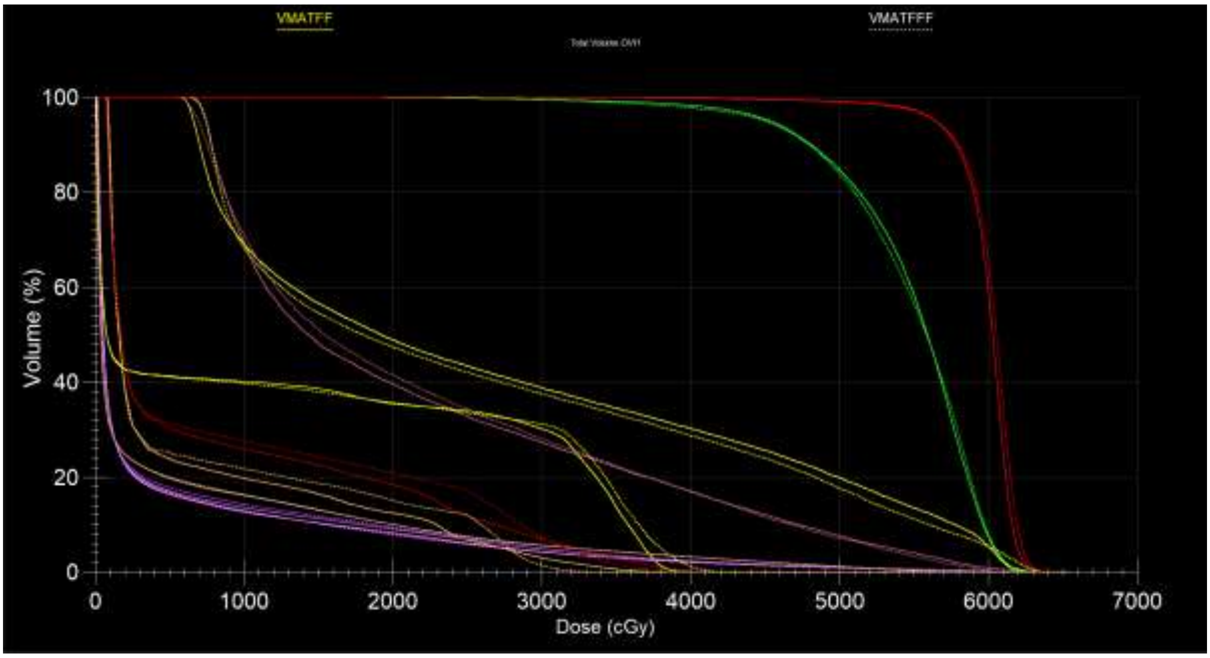

Figure 2.3: DVH analysis for one of the VMAT cases for 6MVFF and 6MVFFF

Plan evaluation strategy

Dose-volume histogram (DVH) analyses were performed with the DVH estimation algorithm for target volumes and OARs. Dosimetric indices, i.e., conformity index (CI), homogeneity index (HI), integral dose (ID), and Monitor Units were evaluated.

Conformity Index

Conformity index (CI) quantitatively assesses the quality of the treatment plan. It represents how well a target is confined with a prescription isodose line; it establishes a relationship between isodose distribution and target volume.

$CI= V_{RI}/TV$--------- (1)

where,

V_{RI} = Reference isodose volume ($V_{95\%}$ is taken as reference isodose volume) and

TV = Target volume.

Homogeneity Index

Homogeneity index (HI) is a measure of dose distribution uniformity across target volume.

$HI = (D_{2\%} - D_{98\%}) / (D_{50\%})$ --------(2)

where $D_{2\%}$, $D_{50\%}$ and $D_{98\%}$ are the doses received by 2%, 50%, and 98% volumes of PTV, respectively. The homogeneity value ranges from 0 to 1. The ideal value of the HI is 0. A higher value represents a lack of homogeneity.

Integral Dose

Integral Dose (ID) refers to the whole energy absorbed within the organ. It is well known that ID is directly associated with secondary malignancy as an increase of energy deposition in healthy tissues might play a major role in the induction of secondary cancers. For simplicity, it is considered as uniform density for the whole-body volume. equation can be rewritten as,

$ID = D_{mean}$ (Gy) X V_{mean} (cc)-------(3)

where,

D_{mean} =The mean organ dose

V_{mean} =Organ Volume

3. Results and Discussion

The conformity index equal to 1 corresponds to the ideal dose coverage or good conformance. When CI is greater than 1, it indicates that irradiated volume exceeds the target volume and covers part of the healthy tissues. Similarly, when the CI is less than 1 it means that the target volume is partially irradiated. The conformity index calculated for 16 patients for both 6MV and 6MVFFF were tabulated in Table 3.1. The CI analysed for 6MV resulted in the mean and standard deviation of 1.163±0.0928 respectively and for 6MVFFF resulted in the mean and standard deviation of 1.167±0.151 respectively.

Table 3.1: Conformity Index comparison

CI	
6MVFF	**6MVFFF**
1.172	1.147
1.014	1.036
1.355	1.561
1.110	1.098
1.128	0.869
1.047	1.102
1.103	1.086
1.124	1.131
1.299	1.337
1.248	1.246
1.108	1.134
1.146	1.155
1.109	1.148
1.189	1.139
1.175	1.157
1.285	1.330

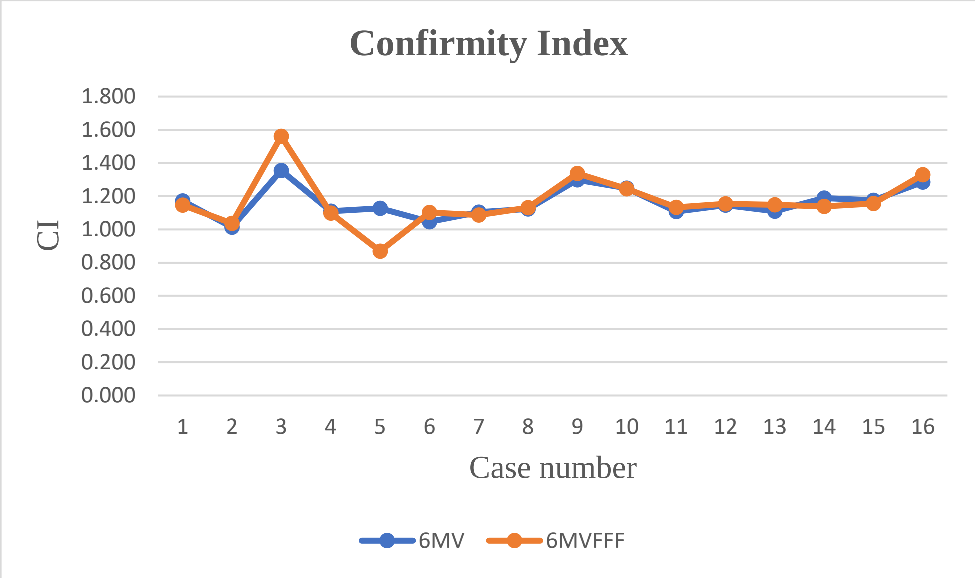

Figure 3.1: Conformity index comparison for 6MV and 6MVFFF beams

Homogeneity index is used to measure of dose distribution uniformity across target volume. The homogeneity value ranges from 0 to 1. The ideal value of the HI is 0. A higher value represents a lack of homogeneity. The Homogeneity index calculated for 16 patients for both 6MV and 6MVFFF were tabulated in Table 3.2. The HI analysed for 6MV resulted in the mean and standard deviation of 0.120±0.031 respectively and for 6MVFFF resulted in the mean and standard deviation of 0.141±0.033 respectively.

Table 3. 2: Homogeneity Index comparison

HI	
6MVFF	**6MVFFF**
0.118	0.098
0.147	0.133
0.099	0.134
0.180	0.180
0.102	0.183
0.045	0.188
0.120	0.112
0.161	0.164
0.108	0.141
0.085	0.091
0.139	0.149
0.109	0.122
0.121	0.150
0.131	0.130
0.114	0.097
0.134	0.189

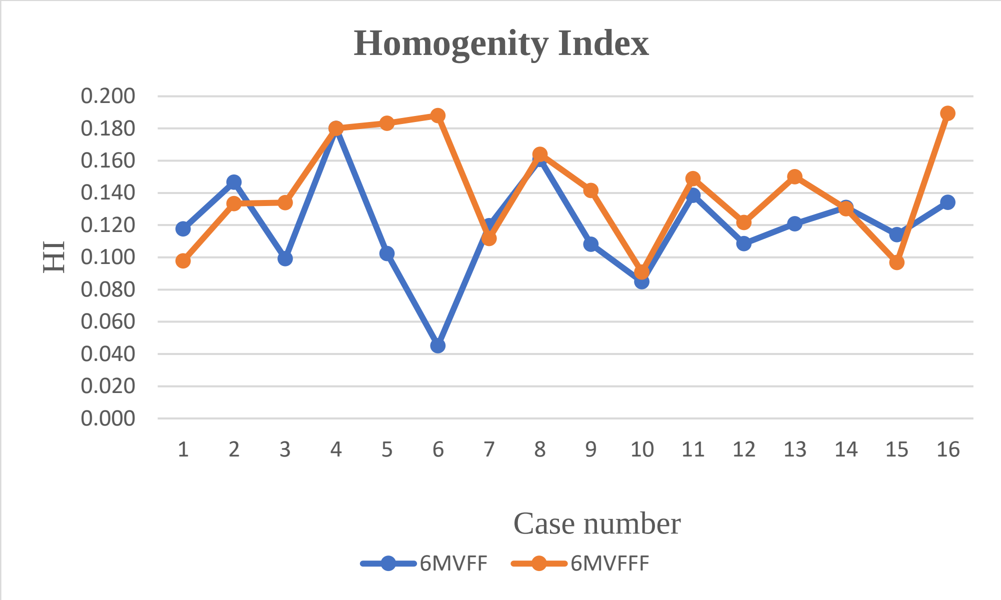

Figure 3.2: Homogeneity index comparison for 6MV and 6MV FFF beam

The OAR Dose to the brainstem analysed for 6MVFF resulted in a mean and standard deviation of 34.54±6.49 respectively and for 6MVFFF it resulted in a mean and standard deviation of 33.99±8.42 respectively.

The OAR Dose to the spinal cord analysed for 6MVFF resulted in a mean and standard deviation of 38.11±3.29 respectively and for 6MVFFF it resulted in a mean and standard deviation of 38.87±4.13 respectively.

The OAR Dose to the Parotid Left analysed for 6MVFF resulted in a mean and standard deviation of 21.88±5.53 respectively and for 6MVFFF it resulted in a mean and standard deviation of 23.61±6.26 respectively.

The OAR Dose to the Parotid Right analysed for 6MVFF resulted in a mean and standard deviation of 25.27±5.24respectively and for 6MVFFF it resulted in a mean and standard deviation of 27.13±5.83respectively.

The OAR Dose to the Mandible analysed for 6MVFF resulted in a mean and standard deviation of 63.18±3.02 respectively and for 6MVFFF it resulted in a mean and standard deviation of 64.39±2.33 respectively

Integral Dose is calculated from equation **ID = D $_{mean}$ X V $_{mean}$.** The Integral Dose for both 6MVFF and 6MVFFF are tabulated in table 3.3. The Integral Dose analysed for 6MVFF resulted in a mean and standard deviation of 90961.25 ± 26124.40 respectively and for 6MVFFF it resulted in a mean and standard deviation of 88911.3±25583.97 respectively.

Table 3.3: Integral Dose comparison

Integral Dose	
6MVFF	**6MVFFF**
126973.84	125621.030
113183.11	114551.113
91636.75	91591.804
113698.37	113863.499
152650.88	146659.072
70645.43	70213.929
97890.35	94015.171
62543.19	60884.852
76068.35	74847.998
78541.06	76269.212

68307.52	67511.709
63552.95	61535.401
58567.45	57026.206
101792.67	96912.201
84938.37	82459.625
94389.78	88617.861

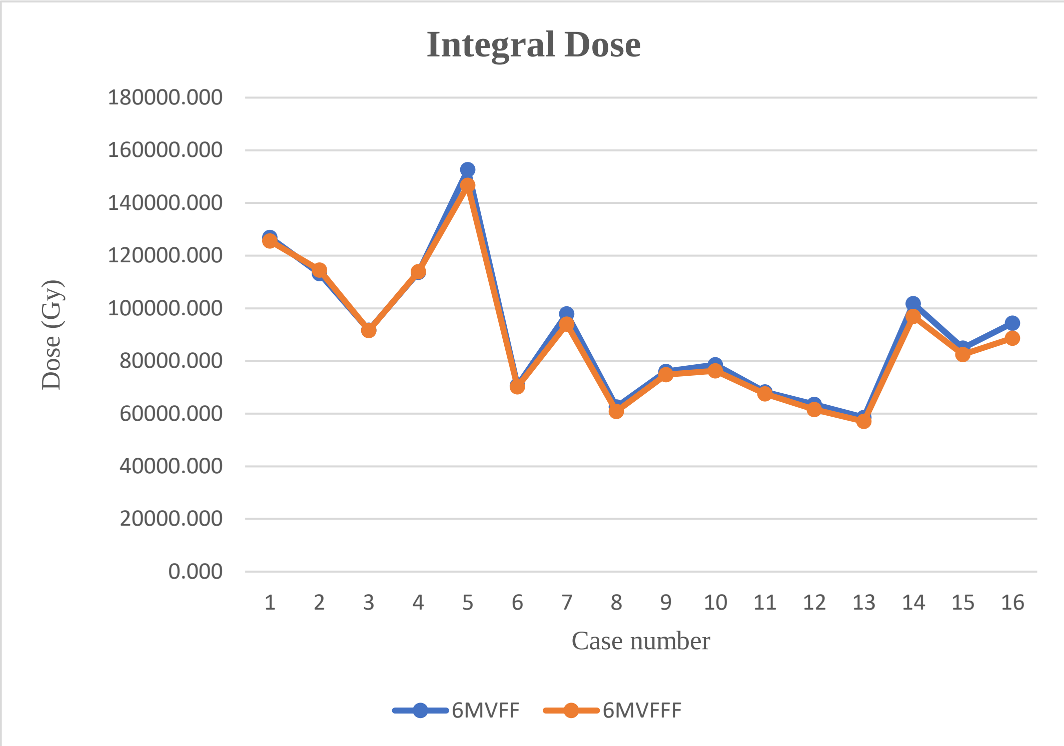

Figure 3.3: Comparison of ID calculated for 6MV And 6MV FFF beams

The last factor considered for analysis is Monitor Units. Monitor Units represents the time taken for treatment delivery. Which means that as lower the MU less treatment time. From the Table 3.4 it can be seen that MU is higher for 6MV FFF compared to 6MV FF. The figure below shows MU Comparison. The Monitor Units analysed for 6MVFF resulted in a mean and standard deviation of 1228.87±107.74 respectively and for 6MVFFF it resulted in a mean and standard deviation of 1621.93±167.20 respectively.

Table 3.4: Monitor Unit comparison

Sl. no.	**6MV FF**	**6MVFFF**
1	1311.54	1803.4
2	1417.35	1752.13
3	1032.34	1434.05
4	1238.87	1653.28
5	1322.61	1792
6	1179.00	1550
7	1199.00	1628.72
8	1162.00	1624.43
9	1195.45	1511.02

10	1224.76	1618
11	1336.64	1626.35
12	1265.37	1431.56
13	1118.29	1643
14	1326.79	1749.87
15	1038.28	1229.25
16	1293.60	1903.83

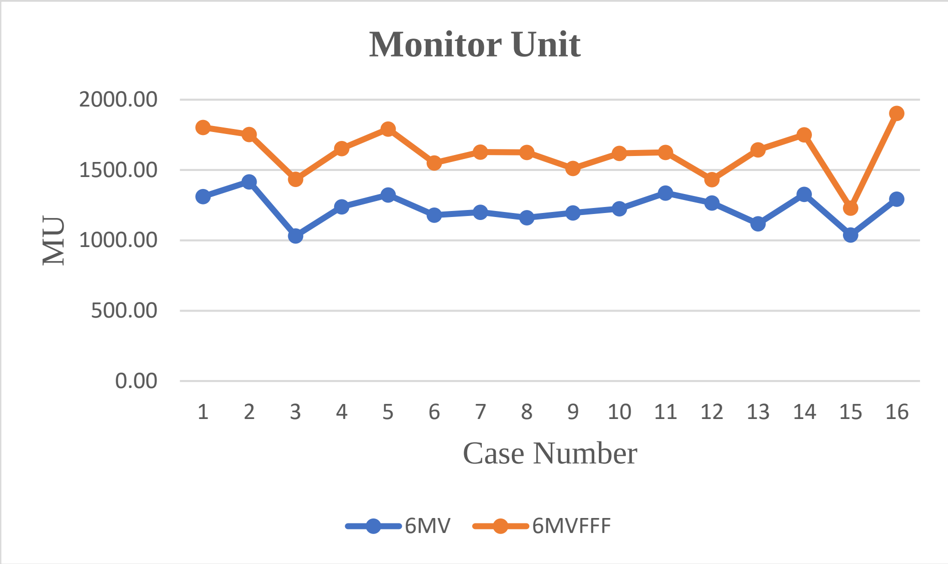

Figure 3.4: Comparison of MU calculated for 6MV And 6MVFFF

4. Conclusion

The above study concludes that 6MV FFF plans can effectively decrease the integral dose and spillage with reduced treatment delivery time. 6MV FFF plans provides a comparable target coverage, dose to organ at risks with respect to 6MV FF plans.

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