RESEARCH ARTICLE

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Dosimetric Comparison of Stereotactic Radiosurgery and Stereotactic Radiotherapy Planning Techniques with Apex 2.5mm and Agility 5mm Multileaf Collimator for Intracranial Cancer

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Abstract

Objective: Apex 2.5mm micro-Multileaf Collimator (mMLC) provides conformal dose distribution to the tumor in stereotactic radiosurgery (SRS)/stereotactic radiotherapy (SRT) treatments. Since it is an add-on device to the linear accelerator (LINAC), it requires extra commissioning for quality assurance (QA) and treatment. Agility is an in-built MLC having a 5mm multileaf collimator (MLC) width that is capable of providing better outcomes for SRS/SRT. Hence, this study compares the apex-based dynamic conformal arc therapy(DCAT) and agility-based volumetric-modulated arc therapy (VMAT) treatment plans using 6MV flattening filter-free (FFF) radiation beams. **Methods:** The population included thirty patients with brain metastasis(BM) with median age of 58 years(35y-75y) treated between 2021 and 2024. The selected patients were grouped into five categories based on the dose to be delivered, with six patients in every group. The dose delivered in groups I, II, III, IV, and V were 16Gy/1fraction(Fr), 18Gy/1Fr, 20Gy/1Fr, 24Gy/1Fr, and 25Gy/5Fr respectively. Two treatment plans were generated for every patient using the apex-based DCAT and agility-based VMAT technique with 6 MV-FFF photon beam energy using Monaco (5.11.03) treatment planning system(TPS). **Result:** The planning target volume (PTV) and gross tumor volume (GTV) coverage were excellent in both planning techniques. Conformity index (CI), gradient index (GI), selectivity index (SI), and coverage ratios were similar in both plans. The homogeneity index (HI) was superior with apex-based plans. Total monitor units (MUs) were higher in agility-based plans, resulting in high beam-on time. **Conclusion:** As the apex is an add-on device to the collimator of the LINAC machine, it requires additional time for commissioning and QA before the treatment. Agility, with in built 5mm MLC, does not require extra commissioning. Dosimetrically, the treatment plans achieved with agility were comparable with apex-based plans except for total MUs. If this is kept aside, 5mm MLC agility-based VMAT FFF plans are capable of giving good outcomes for SRS/SRT treatments.

Keywords: Radiosurgery- dynamic conformal arc therapy- VMAT- Brain Metastasis- micro MLC

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Introduction

A brain tumor, often called an intracranial tumor, is an unusual growth of tissue that forms from the cells inside the brain. In 2020, Global Cancer Observatory (GLOBOCAN) reported 308,102 new brain cases, along with 251,329 related deaths. The Indian Council of Medical Research (ICMR) found in 2021 that brain tumors represented 1.6% of all cancer cases in the country [1]. Brain tumors are uncommon and have a poor prognosis overall [2]. In up to 30% of adult cancer patients, brain metastases are common [3]. They are typically induced by cancer located primarily in the lung, breast, or gastrointestinal tract, which can lead to a high mortality rate [4].

Following a tumor diagnosis, various treatment methods are employed to address brain metastases (BM),

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including surgical resection, radiation therapy (RT), and concurrent or adjuvant chemotherapy that make up the standard of care [4–6]. Stereotactic radiosurgery (SRS), whole brain radiation therapy (WBRT), stereotactic radiotherapy (SRT), intensity modulated radiation therapy (IMRT), volumetric modulated arc therapy (VMAT), and dynamic conformal arc therapy (DCAT) are the forms of RT used to treat BM [4, 7, 8].

SRS and SRT aim to improve tumor management with reduced neurocognitive impairment. SRS involves a single, high dose of radiation, providing local control and comparable tumor control rates to surgery. SRT follows the same guidelines but is fractionated. SRS is recommended for patients with lesions up to 3-4 cm in diameter and 1 to 4 BM. This is basically for effective local control and to lower the risk of radiation necrosis, which rises with tumor volume [3, 9–11]. SRS delivers radiation that is highly conformal to the lesion and has a quick dose fall-off at the treatment volume's edge [12]. It may prolong survival and prevent the need for invasive surgery in patients with a single small lesion while maintaining local control [13]. Brain tumors can be shrunk, and the tumor cells are killed by radiation therapy, which uses X-rays and gamma rays [5].

The use of a thermoplastic cranial mask immobilization system for the frameless treatment delivery has essentially superseded traditional frame-based radiosurgery for BM with the introduction of linear accelerators (LINACs) with image-guided radiation therapy (IGRT) capability [11, 14]. LINAC-based SRS has become more sophisticated with its capability to utilize IMRT and VMAT techniques, offering the potential for enhanced organs-at-risk (OAR) sparing [15]. When it comes to delivering SRS with a LINAC, the standard approach is to use DCAT with non-coplanar beams [9]. This method makes it possible to achieve a plan quality on LINACs that is similar to robotic methods [10]. However, due to advancements in RT devices, many institutions have come to favor VMAT. Using inversed planning methods, VMAT allows for the adjustment of target conformity, dose gradient, and doses to OARs [4, 9].

In the past 15 years, multileaf collimators (MLCs) have developed in relation to both field size and the width of their individual tungsten leaves. It seems reasonable to presume that reducing MLC leaf width could have an effect on target dose conformity and/or the steepness of the dose gradient [16, 17]. One such device, designed to improve conformity to the target, is an externally attached additional collimating device with a micro-multileaf collimator (mMLC) [18]. These are typically add-on devices that are used with non-dedicated LINAC units [19]. The mMLC has a high-resolution collimation system with a width of 2.5mm at the isocentre [20]. Elekta's latest mMLC model is apex, designed to attach to the LINAC head for use in SRS and SBRT. Weighing 50 kg, the apex is made up of 56 pairs of tungsten alloy leaves with a nominal width of 2.5mm at the isocenter, allowing for a maximum field size of 12 cm x 14 cm. The leaf design features a double focus and lacks a tongue-and-groove structure [21]. This would facilitate the delivery of a conformal radiation dose to the tumor with a steep dose gradient beyond the tumor, thus better sparing the surrounding normal tissues [20].

Since LINACs with fine MLC leaf widths (4 to 5mm leaf width at isocenter) are now commonly available, clinically acceptable treatment plans for SRT may be achievable without the need for extra devices, which increase treatment setup time and require additional commissioning [19]. Our current delivery platforms with 5mm MLC can generate clinically acceptable plans for most SRS cases. While plans can be enhanced further with 2.5mm MLC for planning target volume (PTVs)<1cc, but there are concerns regarding the practicality of using an add-on apex device [22]. More recent advancements in high-dose flattening filter-free (FFF) beams have substantially decreased the likelihood of patient mobility. As a result, the FFF-VMAT LINAC therapy modality is now a practical instrument for carrying out SRT [23]. The mMLC and FFF beams are two examples of the consistent advancements in LINACs during the last ten years. It makes sense that these developments should result in a notable improvement in dosimetry when combined with VMAT [24].

Although apex for SRS/SRT planning gives good dose distribution, it also has technical issues with mMLC and gantry calibration, the fixing of which extends the treatment's overall duration. Also, there is a disadvantage of reduced clearance between the patient and collimator, which limits the utilization of non-coplanar beam directions [20]. If a plan with excellent output is available with agility-based (5mm MLC) VMAT-FFF photon beam energy, then the treatment duration is expected to be reduced compared to apex-based delivery. Hence, this study aimed to compare SRS/SRT treatment plans performed with apex (2.5mm mMLC) and agility (5mm MLC), using 6MV VMAT-FFF radiation beams to check the tumor coverage and dose to the OARs.

Materials and Methods

Patient selection

Thirty patients were prospectively considered for the study after approval from the Institutional Ethics Committee, Kasturba Medical College and Kasturba Hospital, Manipal Academy of Higher Education Manipal (IEC427-2021, approved on 8th August 2021) and Clinical Trials Registry, India (registration number CTRI/2021/11/037842 approved on 8th November 2021). The population included patients with BM having a median age of 58 years (35y to 75y) who were treated in the year between 2021 and 2024 at our institute. The selected 30 patients were grouped into five categories based on the dose to be delivered to the patient with six patients in each group. The dose delivered in groups I, II, III, IV, and V were 16Gy/1fraction (Fr), 18Gy/1Fr, 20Gy/1Fr, 24Gy/1Fr, and 25Gy/5Fr respectively. The eligibility criteria for the patient selection were based on the guidelines given for SRS/SRT [25].

Patient Immobilization and Contouring

A Fraxion patient-specific cranial immobilization system (Fraxion, P10106-103, Elekta) including a computed tomography (CT) adaptor, tabletop adaptor,

vacuum cushion, thermoplastic mask, and Fraxion stereotactic frame was used to immobilize the chosen patients. Fraxion's vacuum cushions are specifically utilized as headrests for patients, offering repeatable treatment setup and accurate head alignment. Every cushion was customized for every patient and utilized during the course of therapy [26]. A thermoplastic mask was used to immobilize the patient. The patient's CT image with a slice thickness of 1mm was acquired with the Fraxion stereotactic frame and marking sheet. A stereotactic frame was used to locate the tumor in SRS/SRT. It has three Z-shaped radiopaque markers that are visible in the axial cut CT image as nine dots that act as fiducials for the identification of the target coordinates. The marking sheet has three coordinates, x, y, and z, which are used to locate the tumor in the coordinate system. This makes it convenient to position patients according to the treatment isocenter. The acquired CT images were exported to the Monaco 5.11.03 treatment planning system (TPS). Magnetic resonance imaging (MRI) is considered superior to CT in soft-tissue discrimination of the brain. The rigid image registration was carried out between MRI (Philips Achieva, 1.5 Tesla) and CT (Philips, Brilliance 16 Big Bore) and mapping of the structures was performed to avoid any misinterpretation. For registration purposes, T1-weighted fluid-attenuated inversion recovery (FLAIR) MRI images with contrast enhancement and T2-weighted FLAIR MRI images were utilized. Following image registration, the gross tumor volume (GTV), PTV (GTV plus 1 to 2 mm margin in all dimensions), and important anatomical organs, including the normal brain, optic nerves, optic chiasma, brainstem, eyes, lens, cochlea, etc., were delineated [10, 27].

Treatment Planning

The selected cases were planned using SRS/SRT treatment techniques following the dose constraints and the guidelines [25, 28–30] using the Monaco 5.11.03 (Elekta, 2016) TPS. Two plans were made for every patient. The first plan was generated with the DCAT technique using 6MV-FFF photon beam energy using apex mMLC (2.5mm). The mMLC is an additional attachment to the collimator of the Elekta Versa high-definition (HD) LINAC consisting of mMLC with a 2.5mm width at the isocenter. This high-resolution collimating device is especially used for SRS treatment delivery to facilitate conformal dose distribution around the tumor. The maximum field size provided by the mMLC is 12 cm × 14 cm [31]. The isocenter was placed at the center of the target volume. The number and direction of the arcs were chosen based on the location of the tumor. Couch movement was restricted in some cases, wherever it was practically impossible to move the gantry with the apex to reduce the risk of collision of the gantry with the couch and patient. The LINAC has an inbuilt MLC with a 5mm width at the isocenter, which is also called Agility. The second SRS/SRT treatment plan was performed with VMAT technique using 6MV-FFF photon beam energy with Agility MLC (5mm). The gantry, collimator, and couch angles were determined based on the tumor location and kept constant in both treatment plans. The treatment plan was implemented using the same gantry couch combinations as with apex. The Monte Carlo (MC) algorithm was used for optimization purposes. Multiple optimizations in both techniques were performed to achieve the prescribed tumor dose and to bring the dose to the OARs within the given limits. The treatment plans were prescribed to the 80% isodose line.

Plan evaluation

The treatment plans performed using mMLC and agility were compared using Monaco TPS. The quality of the treatment plans was checked using quality indices such as target coverage (TC), conformity index (CI), homogeneity index (HI), gradient index (GI), selectivity index (SI) and organ at risk (OAR) doses. CI was calculated using the formula TV PIV 2/ (TV × PIV). Here, TV is the target volume, and PIV is the prescription isodose volume. The ideal value for CI is 1. As the value of the CI decreases from 1, the quality of the plan also decreases. A value greater than 1 indicates that the tumor volume is over-irradiated, and a value less than 1 indicates a reduction in the dose to the target volume. The HI was calculated as the ratio of the maximum target dose to the prescribed dose. The ideal value for HI is 1. GI was calculated using the formula PV 50%/PIV. PV 50% represents 50% of the prescribed dose covered by the patient volume. The smaller the GI value, the steeper the dose gradient. If multiple targets are close to each other, then combined GI will be performed for the lowest dose prescribed target in the patient. A clinically acceptable plan will have a lower GI value, higher CI value, and higher TC (>95%). Such a plan will provide better tumor coverage and maximum sparing of the normal brain [32,33]. The coverage ratio (CR) was also calculated using the formula Coverage ratio = VPTV100% /PTVvol where VPTV100% is the volume of the PTV receiving 100% of the prescribed dose and PTVvol is total volume of the PTV. The SI was calculated using the formula VPTV100%/VBody100%, where VBody100% is the volume of the patient's body receiving 100% of the prescribed dose [22, 34, 35].

Statistical Analysis

Descriptive statistics was used to describe the data using Jamovi 2.3.26 [36] statistical analysis software. The data's normality was determined using the Shapiro-Wilk test. Since they were found to be not normally distributed, median=mean and standard deviation=interquartile range (IQR)/1.35 were recorded for the continuous variables. The Mann-Whitney U test and multivariate ANOVA were used to find the difference between the two techniques with different parameters. One-way ANOVA was performed to find the difference between the parameters of the six groups having different dose fractionations. A statistically significant difference between the variables was defined as $p<0.05$.

Results

For all the selected thirty brain targets, the mean percentage dose covered by 100% and 95% of the PTV volume in the Apex-based plan was 94.16±3.05

and 99.51±0.49, and in the Agility-based plan, it was 95.52±2.34 and 98.89±1.11, respectively. The mean percentage dose covered by 100% and 95% of the GTV volume in the Apex-based plan was 98.81±1.61 and 99.96±0.11, and in the Agility-based plan, it was 99.47±0.87 and 99.88±0.26 respectively. This means that there is no significant difference in terms of PTV and GTV coverage in the two planning techniques. Agility with 5mm MLC width at the isocentre provides equivalent target coverage similar to apex 2.5mm mMLC. This indicates that with respect to the target coverage, both planning techniques can provide excellent dose distribution to the tumor volume. The coverage ratio was also calculated using the above-mentioned formula, which is 0.94±0.03 and 0.94±0.05 in apex vs. agility-based plans. Although no significant difference was found in the tumor coverage between the two techniques, the agility-based plans show superiority in the PTV and GTV coverage (Figure 1, Table 1).

The quality indices such as CI, HI, GI and SI were calculated using the formula explained in the methodology section. The CI values for apex and agility-based plans were 0.77±0.07 and 0.79±0.06 respectively. No significant difference was found in the CI among the two techniques as the p-value is >0.05. HI for apex plans was 1.13±0.05, and agility was 1.23±0.05 with a p-value less than 0.001 which shows the difference in HI between both planning techniques as the effect size is close to 0.8. The value of HI indicates that the HI is superior in the apex plan compared to agility plans. The GI in the apex and agility plans were 4.89±1.31 and 4.37±1.18 and the overall CR was 0.94±0.03 and 0.94±0.05 in apex and agility-based plans, respectively, having no significant difference between them. The hot areas or the hot spots were measured from 107% to 125%. There was a significant difference found in the hot regions inside the GTV between the apex and agility-based plans. Agility-based plans provided more hot areas compared to apex-based plans. The mean 125% hot areas in apex plans were zero, whereas in agility plans, it was 1.04±2.47 with a p-value less than 0.001, and the volume receiving 125% dose was 0.21±0.63cc (Table 1).

The low dose volumes were calculated in terms of PV50%, PV30%, and PV20%, where PV is the patient volume receiving 50%, 30%, and 20% of the prescribed dose. This is one of the major criteria that was noted down basically to consider the amount of spillage outside the PTV volume. In this study, there was no significant difference in the lower dose spillage in apex and agility plans with a p-value greater than 0.05. Also, it can be noted that the overall spill area outside the PTV volume was lower in agility-based plans which can give the assurance that it is possible to reduce the spill with agility (Table 1)

Table 1. Target Dose and Quality Indices Calculated for the Plans Performed Using Apex Micro-Multileaf Collimator (mMLC) (2.5mm) and Agility Multileaf Collimator (MLC) (5mm)

Parameter	Technique (Mean±SD)		p-value
	Apex	Agility	
Conformity Index (CI)	0.77±0.07	0.79±0.06	0.15
Homogeneity Index (HI)	1.13±0.05	1.23±0.05	<.001
Gradient Index (GI)	4.89±1.31	4.37±1.18	0.096
Selectivity Index (SI)	0.82±0.08	0.83±0.07	0.582
Coverage Ratio (CR)	0.94±0.03	0.94±0.05	0.075
PTV 100%	94.16±3.05	95.52±2.34	0.076
PTV 95%	99.51±0.49	98.89±1.11	0.022
GTV 100%	98.81±1.61	99.47±0.87	0.107
GTV 95%	99.96±0.11	99.88±0.26	0.011
PTV 107%	44.96±20.24	75.32±10.99	<.001
PTV 107% (cc)	5.15±5.04	8.88±7.49	0.028
PTV 110%	19.88±18.13	58.68±19.15	<.001
PTV 110% (cc)	2.32±3.23	7.29±7.03	<.001
PTV 115%	3.01±6.29	30.17±22.94	<.001
PTV 115% (cc)	0.47±1.10	4.06±5.71	<.001
PTV 120%	0.01±0.04	9.98±14.52	<.001
PTV 120% (cc)	0.002±0.01	1.75±3.44	<.001
PTV 125%	0±0	1.04±2.47	<.001
PTV 125% (cc)	0±0	0.21±0.63	<.001
PV 50% (cc)	53.75±40.11	45.74±30.92	0.478
PV 30% (cc)	122.36±90.27	116.46±80.93	0.889
PV 20% (cc)	222.75±168.41	206.18±134.45	0.924
Max Target Dose (Gy)	23.42±3.94	25.36±4.57	0.037

* Here the median and IQR (Interquartile range) is converted into Mean ± SD; Mean, Median; SD, IQR/1.35.; PTV, Planning Target Volume; GTV, Gross Tumor Volume; PV, Patient Volume

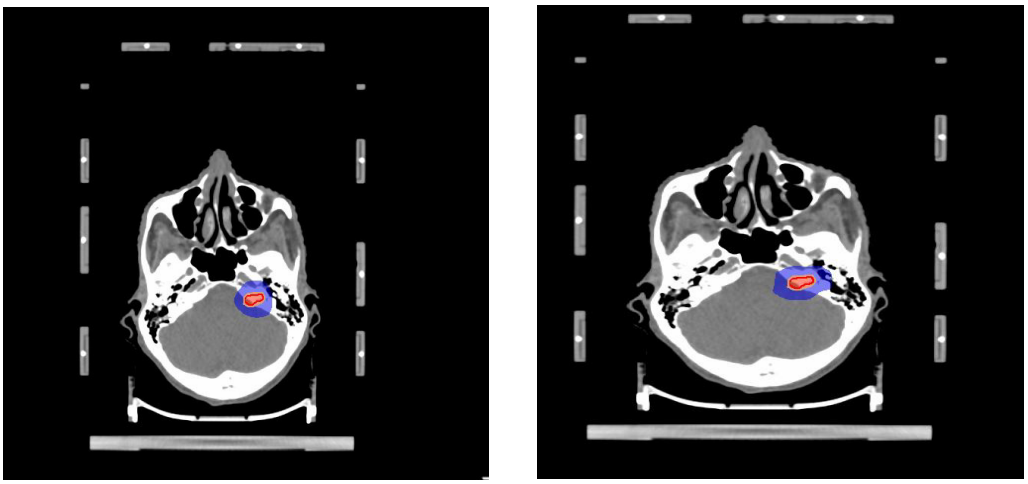

Figure 1. Comparison of Dose Distribution in Apex Micro-Multileaf Collimator (mMLC) (2.5mm) based dynamic conformal arc therapy (DCAT) plan (Left) with Agility multileaf collimator (MLC) (5mm) based volumetric modulated arc therapy (VMAT) plan (Right) with 6MV flattening filter-free (FFF) beam. 125% of the prescribed dose (16Gy/1Fraction),●100%,●95%,●50%

without affecting the tumor coverage.

The plans were also examined on the basis of the dose received by the OARs. Regarding the organ doses, it was found that there was no discernible difference between the agility and apex-based plans, with the p-value being higher than 0.05. But it can also be noted that, though statistically, there is no difference between the plans, we can see in this study that, agility-based plans are superior in lowering the dose to the surrounding organs, better sparing the OARs as the low dose spill outside the PTV was lower, which intern contributed to the reduced OAR dose. It can also be noted that, although the OAR doses in some organs were slightly higher, and in some, it was slightly lower than the agility, the doses were well within the dose constraints for all the organs (Table 2).

There was a huge notable difference in the MUs calculated for agility and apex-based plans whose p-value is lower than 0.01. The agility-based plans require more MUs to deliver the best acceptable plan, which in turn increases the treatment execution duration. The MUs in apex-based and agility-based plans were 2271.15±889.64 and 4017.13±1633.96, respectively. So, agility plans required almost double the MUs than apex-based plans (Table 2).

Table 2. Organ at Risk Doses (OAR) and Total Monitor Units (MU) Calculated for the Plans Performed Using Apex Micro-Multileaf Collimator (mMLC) (2.5mm) and Agility multileaf collimator (MLC) (5mm)

Organ at Risk Dose in Gy	Technique (Mean±SD)		p-value
	Apex	Agility	
Rt Optic Nerve (0.1cc)	0.54±0.61	0.50±0.73	0.404
Lt Optic Nerve (0.1cc)	0.68±0.83	0.65±0.89	0.663
Optic Chiasm (0.1cc)	0.93±1.10	0.84±1.12	0.569
Lt Cochlea (Mean)	3.37±5.19	2.96±4.40	0.767
Rt Cochlea (Mean)	5.42±8.09	5.21±8.25	0.728
Brainstem (0.1cc)	9.03±8.31	8.91±8.57	0.773
Whole Brain-PTV D10cc	14.35±4.86	13.05±3.89	0.314
Whole Brain-PTV D50%	0.24±0.33	0.20±0.37	0.036
Whole Brain-GTV D10cc	15.49±5.14	14.40±4.42	0.423
Whole Brain-GTV D50%	0.20±0.13	0.15±0.12	0.024
Rt Lens (0.1cc)	0.27±0.37	0.29±0.54	0.559
Lt Lens (0.1cc)	0.34±0.43	0.30±0.37	0.61
Rt Eye (0.1cc)	0.63±0.68	0.79±1.04	0.802
Lt Eye (0.1cc)	0.70±0.73	0.82±0.99	0.929
Spinal Cord (0.1cc)	1.38±4.56	1.29±4.19	0.668
Skin (0.1cc)	9.05±5.73	9.41±5.01	0.485
Total MU	2271.15±889.64	4017.13±1633.96	<.001

* Here the median and IQR (Interquartile range) is converted into Mean ± SD; Mean, Median; SD, IQR/1.35; PTV, Planning Target Volume; GTV, Gross Tumor Volume; PV, Patient Volume

Discussion

This study compares the SRS and SRT treatment plans performed with apex 2.5mm mMLC and agility 5mm MLC offered by Elekta, planned with Monaco treatment planning software. SRS and SRT using linear accelerators (Linac) are commonly employed to treat small intracranial tumors and malformations [24]. Using LINACs for SRT in cases of BM is considered a safe treatment method [37]. Recent developments in linac-based technologies, such as VMAT, MLCs, and image-guidance systems, have produced linac-based treatments with high accuracy, steep gradients, and high conformance to the complicated geometric targets, and reduce the dose spread to normal tissues [23, 38]. Two widely utilized methods for planning SRT with conventional LINACs that have MLCs are DCAT and VMAT [39]. Moreover, the application of FFF beams in SRS/SRT has resulted in a reduction of the treatment duration [13]. The DCAT approach provides a conformal treatment modality akin to intensity-modulated treatments with a larger and fewer number of segments without varying the intensity [40, 41].

As explained earlier, the apex is the recent model manufactured by Elekta which delivers a conformal dose to the target with a steep dose gradient beyond the tumor, thus better sparing the nearby normal tissues [21]. Additionally, the high weight of an apex system causes the gantry to sag and could cause collisions with the patient or the other parts of the machine, if there is no proper selection of beam angulation and careful handling. Also, it takes time to install and requires quality assurance before each usage. It is also unlikely to be used frequently. Using the apex method to lower the GI and R50% values may be advantageous for PTVs less than 1cc. The absence of a touch guard, the requirement to offset the isocenter laterally by more than 4cm from the midline, and the difficulty in executing a full arc cone beam acquisition with this isocenter position are some of the issues that still exist with the usage of an add-on MLC [22]. These mMLC with lesser leaf widths at isocenter are generally the add-on devices which are basically used with the machines that are not dedicated for SRS/SRT treatments. It might be feasible to create clinically acceptable treatment plans for SRS/SRT without the need for specialized add-on devices, as the LINACs with fine MLC leaf widths of 4 to 5 mm at isocenter are now regularly available and used for treatments [19]. The current 5mm MLC can be used to create a strategy that works for most QA scenarios [22].

With respect to the target coverage with 100% and 95% of the dose to the PTV and GTV, our study has shown similar results in both apex and agility-based plans. Also, the overall coverage ratio was found to be very similar in both planning techniques. So, the leaf widths, 5mm and 2.5mm, do not affect the dose coverage to the target volume. Jacqueline et al. performed a study where they compared mMLC with 5mm MLC for SRT. They found identical PTV coverage in both 3mm and 5mm based plans. In both collimators, the minimum dose to PTV was likewise comparable. However, a significant difference was found in the CI between 3mm and 5mm MLC plans. The 5mm plans indicated an inferior isodose conformation to the PTV. Although the difference was very small, it was significant [19]. It was found that the reduced MLC width has only marginal advantages [42] on the plan outcome. A 3mm MLC improves target conformity and normal tissue preservation compared to a 5mm MLC, though differences may not always be clinically significant. Smaller MLC widths also provide better sparing of critical structures, and VMAT is generally superior to IMRT and DCAT for stereotactic radiosurgery. Additionally, Non-coplanar VMAT offers better dose coverage, conformity, and brain sparing than DCAT and coplanar VMAT, despite longer treatment times [9, 15, 19, 24, 43].

CI and HI are the basic tools used in radiotherapy to evaluate a treatment plan's quality [44]. In our study, we found no significant difference in the CI between the two widths of MLC, which clearly says that the MLC width has the least impact on the conformal dose distribution of the tumor volume. It was also found in one study that the CI was comparable in apex-based DCAT and agility-based VMAT treatments. HI represents the degree of homogenous radiation dose distribution inside the target volume [44, 45]. We found a small difference in the HI between the apex and agility-based plans. Though the difference was very small, it showed statistical significance with a p-value lower than 0.05. Apex-based plans were superior in offering good HI compared to agility plans. In one of the studies performed by Isabella et al. DACT and VMAT plans were compared dosimetrically, they also found that DCAT plans were superior in terms of homogeneity of dose distribution to the target volume [39].

GI is used to describe the dose fall-off outside the target volume [45, 46]. Some studies found that the GI in DCAT-based plans was better compared to the VMAT plans for SRS [39]. Anas et al. [4] found that the GI was best in the non-coplanar (Nc) VMAT planning technique compared to coplanar VMAT and DCAT plans. We found that both apex and agility plans gave similar results with GI. Although there was a slight difference between them, with agility plans being superior, it did not show any statistical significance. This gives us more understanding that it is possible to reduce low-dose spills such as 50%, 30%, and 20% of the prescribed dose by rigorous optimization and with the combination of the noncoplanar beams in agility-based VMAT plans. We also noted down the volume receiving 30% and 20% of the prescribed dose outside the target volume. It was found that there was no significant difference between the two planning techniques. The results were similar, with very slight differences between them, with agility being slightly superior in reducing the low-dose spill and maintaining the other parameters to achieve the best plan. When evaluating a radiotherapy treatment plan, the SI is a statistic used to determine how well the plan spares the normal tissues around the target volume [34, 35, 47]. In our study, both agility and apex-based plans showed very similar SI having no statistically significant difference.

In our study, MUs for agility-based plans were higher, in fact, two times more than the apex-based plans in most of the cases. In order to give the best plan that meets all the required dose constraints, in general, VMAT plans offer higher MUs compared to DCAT plans. Even though the

MU and related beam-on times were higher with VMAT than the DCAT plans, the results of our dosimetric study clearly showed that the VMAT was capable of providing completely conformal SRS/SRT plans with steeper dose falloff beyond the target volumes. Lower MU and shorter beam-on times, however, should not be regarded as the only requirements for managing intracranial lesions with SRS/SRT, instead, other plan quality indices, such as the GI, HI, and CI, should be carefully taken into consideration when selecting the best SRS/SRT plan for each patient [48]. Nonetheless, VMAT planning accomplishes a superior TC at the cost of an increase in MU. Although the outcomes obtained from DCAT treatments using apex are in some way better than those from the same treatments that involve only agility, VMAT treatments yield superior outcomes, albeit with higher MUs [4, 10, 49].

As we discussed earlier, the major purpose of small-width mMLC was to improve the conformity of the prescribed dose to the target volume in SRS/SRT with the combination of FFF radiation beams, which successfully reduces the treatment duration due to its high dose rate, resulting less MUs [18, 23]. Since the apex, with 2.5mm mMLC width at the isocentre, is an add-on device to the collimator of the LINAC, it requires additional commissioning before every treatment, and the beam angulation during the planning has to be carefully decided due to the reduced clearance between the apex and the patient or other parts of the LINAC. Also, it requires manpower to attach this device to the LINAC due to its increased weight [19-21]. So, it has to be noted that although beam on time is more in 5mm width agility-based plans, it does not require extra commissioning duration. The pilot study was performed in 2023 with five SRS cases to gain initial understanding and insight.

In conclusion this study compared 2.5mm mMLC apex-based DCAT treatment plans with 5mm MLC agility-based VMAT plans using a 6MV-FFF beam. The PTV and GTV coverage was excellent in both planning techniques. CI, GI, SI, and coverage ratios were similar in both plans. HI was superior with apex-based plans. Total MUs were higher in agility-based plans, resulting in high beam on time. Hot spot regions were higher in agility-based plans. As the apex is an add-on device to the collimator of the LINAC machine, it requires additional time for commissioning and QA before the treatment. Agility, with in built 5mm MLC, does not require extra commissioning. Dosimetrically, the treatment plans achieved with agility were comparable with apex-based plans except for total MUs. If this is kept aside, 5mm MLC agility-based VMAT-FFF plans are capable of giving good outcomes for SRS/SRT treatments.

Author Contribution Statement

Ms. Rechal Nisha Dsouza- Data collection, data analysis, data interpretation, article drafting; Dr. Suresh Sukumar-Concept and Design of the work; Dr. Krishna Sharan- Concept and Design of the work; Mr. Srinidhi G Chandraguthi-Critical revision of the article; Dr. Shreekripa Rao-Critical revision of the article; Dr. Shirley Lewis-Critical revision of the article; Dr. Senthil Manikandan-Critical revision of the article; A

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Ethical Declaration

The study is approved by the Institutional Ethics Committee, Kasturba Medical College and Kasturba Hospital, Manipal Academy of Higher Education Manipal (IEC427-2021) on 8th August 2021

Study Registration

The study is registered under Clinical Trials Registry, India; registration number CTRI/2021/11/037842, on 8th November 2021.

Availability of the Data

Data can be provided by the author at the request of the reader.

Conflict of interest

The authors declare that there is no competing interest involved in this research work.

References

1. Paul M, Goswami S, C GR, Bora G. Clinico-epidemiological Profile of Primary Brain Tumours in North-Eastern Region of India:A Retrospective Single Institution Study. Asian Pacific J Cancer Care. 2023;8(2):333–6. https://doi.org/10.31557/APJCC.2023.8.2.333
2. Yeole BB. Trends in the brain cancer incidence in india. Asian Pacific J Cancer Prev. 2008;9(2):267–70.
3. Ladbury C, Pennock M, Yilmaz T, Ankrah NK, Andraos T, Gogineni E, et al. Stereotactic Radiosurgery in the Management of Brain Metastases: A Case-Based Radiosurgery Society Practice Guideline. Adv Radiat Oncol. 2024;9(3):101402. https://doi.org/10.1016/j.adro.2023.101402
4. Anas A, Redouan EB, Youness K, Sanaa N, Mounir M, Abdelouahab A, et al. Dynamic conformal arc therapy, coplanar and non-coplanar volumetric modulated arc therapy, in brain tumour ballistics: A dosimetry comparison experience of Casablanca Cancer Centre. Onkol i Radioter. 2023;17(8):244–8.
5. Rasheed S, Rehman K, Akash MSH. An insight into the risk factors of brain tumors and their therapeutic interventions. Biomed Pharmacother. 2021;143(July):112119. https://doi.org/10.1016/j.biopha.2021.112119
6. Birzu C, French P, Caccese M, Cerretti G, Idbaih A, Zagonel V, et al. Recurrent glioblastoma: From molecular landscape to new treatment perspectives. Cancers (Basel). 2021;13(1):1–29. https://doi.org/10.3390/cancers13010047.
7. Bernard ME, Wegner RE, Reineman K, Heron DE, Kirkwood J, Burton SA, et al. Linear accelerator based stereotactic radiosurgery for melanoma brain metastases. J Cancer Res Ther. 2012;8(2):215–21. https://doi.org/10.4103/0973-1482.98973
8. Vlachos N, Lampros MG, Filis P, Voulgaris S, Alexiou GA. Stereotactic radiosurgery versus whole-brain radiotherapy after resection of solitary brain metastasis: A systematic review and meta-analysis. World Neurosurg X. 2023;18(September 2022):100170. https://doi.org/10.1016/j.

wnsx.2023.100170
9. Torizuka D, Uto M, Takehana K, Mizowaki T. Dosimetric comparison among dynamic conformal arc therapy, coplanar and non-coplanar volumetric modulated arc therapy for single brain metastasis. J Radiat Res. 2021;62(6):1114–9. https://doi.org/10.1093/jrr/rrab092
10. Hofmaier J, Bodensohn R, Garny S, Hadi I, Fleischmann DF, Eder M, et al. Single isocenter stereotactic radiosurgery for patients with multiple brain metastases: Dosimetric comparison of VMAT and a dedicated DCAT planning tool. Radiat Oncol. 2019;14(1):4–11. https://doi.org/10.1186/s13014-019-1315-z
11. Gupta A, Yadav BS, Ballari N, Das N, Robert N. LINAC-based stereotactic radiosurgery/ radiotherapy for brain metastases in patients with breast cancer. J Radiother Pract. 2022;21(3):351–9. https://doi.org/10.1017/S1460396921000029
12. Peña-Pino I, Chen CC. Stereotactic Radiosurgery as Treatment for Brain Metastases: An Update. Asian J Neurosurg. 2023;18(02):246–57. https://doi.org/10.1055/s-0043-1769754
13. Hartgerink D, Swinnen A, Roberge D, Nichol A, Zygmanski P, Yin FF, et al. LINAC based stereotactic radiosurgery for multiple brain metastases: guidance for clinical implementation. Acta Oncol (Madr). 2019;58(9):1275–82. https://doi.org/10.1080/0284186X.2019.1633016
14. Ohtakara K, Hayashi S, Tanaka H, Hoshi H, Kitahara M, Matsuyama K, et al. Clinical comparison of positional accuracy and stability between dedicated versus conventional masks for immobilization in cranial stereotactic radiotherapy using 6-degree-of-freedom image guidance system-integrated platform. Radiother Oncol. 2012;102(2):198–205. https://doi.org/10.1016/j.radonc.2011.10.012
15. Khong J, Govindaraj R, Ramm D, Edwards S, Roos D. Cochlear sparing in LINAC-based radiosurgery for vestibular schwannoma: a dosimetric comparison of dynamic conformal arc, IMRT and VMAT treatment plans. Radiat Oncol. 2023;18(1):1–7. https://doi.org/10.1186/s13014-022-02188-y
16. Tanyi JA, Kato CM, Chen Y, Chen Z, Fuss M. Impact of the high-definition multileaf collimator on linear accelerator-based intracranial stereotactic radiosurgery. Br J Radiol. 2011;84(1003):629–38. https://doi.org/10.1259/bjr/19726857.
17. Serna A, Puchades V, Mata F, Ramos D, Alcaraz M. Influence of multi-leaf collimator leaf width in radiosurgery via volumetric modulated arc therapy and 3D dynamic conformal arc therapy. Phys Medica. 2015;31(3):293–6. https://doi.org/10.1016/j.ejmp.2015.01.011
18. Jalbout W, Zahr JA, Youssef B, Shahine B. On the feasibility of stereotactic radiosurgery with 5.0 and 10.0 mm mlc leaves as a function of target size and shape. Front Oncol. 2019;9(AUG):3–10. https://doi.org/10.3389/fonc.2019.00741
19. Monk JE, Perks JR, Doughty D, Plowman PN. Comparison of a micro-multileaf collimator with a 5-mm-leaf-width collimator for intracranial stereotactic radiotherapy. Int J Radiat Oncol Biol Phys. 2003;57(5):1443–9. https://doi.org/10.1016/s0360-3016(03)01579-7
20. Marrazzo L, Zani M, Pallotta S, Greto D, Scoccianti S, Talamonti C, et al. Comparison of stereotactic plans for brain tumors with two different multileaf collimating systems. J Appl Clin Med Phys. 2014;15(1):27–37. https://doi.org/10.1120/jacmp.v15i1.4100
21. Ferrer C, Plaza R, Aza Z, Morera R, Serrada A. Ep-2167: Commissioning of the elekta apex dynamic micro multi-leaf collimator. Radiother Oncol. 2018;127:S1197. https://doi.org/10.1016/S0167-8140(18)32476-9.
22. Harron E, Bangiri A, Mckenna A, Pascoe A. Comparison of 5mm and 2 . 5mm MLC for SRS with Monaco VMAT. 2017;November 2016:0–1.
23. Hsu SM, Lai YC, Jeng CC, Tseng CY. Dosimetric comparison of different treatment modalities for stereotactic radiotherapy. Radiat Oncol. 2017;12(1):1–11. https://doi.org/10.1186/s13014-017-0890-0
24. Sarkar B, Pradhan A, Munshi A. Do technological advances in linear accelerators improve dosimetric outcomes in stereotaxy? A head-on comparison of seven linear accelerators using volumetric modulated arc therapy-based stereotactic planning. Indian J Cancer. 2016;53(1):166–73. https://doi.org/10.4103/0019-509X.180815
25. Fatima N, Meola A, Pollom E, Chang SD, Soltys S. Stereotactic Radiosurgery for Large Benign Intracranial Tumors. World Neurosurg. 2020;134:e172–80. https://doi.org/10.1016/j.wneu.2019.10.005
26. Ferrer C, Huertas C, Plaza R, Aza Z, Corredoira E. Dosimetric effects of a repositioning head frame system and treatment planning system dose calculation accuracy. J Appl Clin Med Phys. 2018;19(6):124–32. https://doi.org/10.1002/acm2.12456
27. Djan I, Petrović B, Erak M, Nikolić I, Lučić S. Planiranje radioterapije: Značaj registracija i fuzije CT-MR slike za odredivanje zapremine tumora. Vojnosanit Pregl. 2013;70(8):735–9. https://doi.org/10.2298/vsp110404001d
28. Diez P, Hanna GG, Aitken KL, van As N, Carver A, Colaco RJ, et al. UK 2022 Consensus on Normal Tissue Dose-Volume Constraints for Oligometastatic, Primary Lung and Hepatocellular Carcinoma Stereotactic Ablative Radiotherapy. Clin Oncol. 2022;34(5):288–300. https://doi.org/10.1016/j.clon.2022.02.010
29. SABR UK Consortium. UK SABR Consortium Guidance. 2019;January. Available from: https://www.sabr.org.uk/wp-content/uploads/2019/04/SABRconsortium-guidelines-2019-v6.1.0.pdf.
30. Article : Manuscript - UK Consensus on Normal Tissue Dose Constraints for Stereotactic Radiotherapy Introduction. 2018;
31. Godwin GA, Simpson JB, Mugabe KV. Characterization of a dynamic multi-leaf collimator for stereotactic radiotherapy applications. Phys Med Biol. 2012;57(14):4643–54. https://doi.org/10.1088/0031-9155/57/14/4643
32. Li K. Aperture effect for LINAC-based SRS in small target treatment†. J radiosurgery SBRT. 2016;4(1):21–9.
33. Han EY, Wang H, Luo D, Li J, Wang X. Dosimetric comparison of fractionated radiosurgery plans using frameless Gamma Knife ICON and CyberKnife systems with linear accelerator–based radiosurgery plans for multiple large brain metastases. J Neurosurg. 2020;132(5):1473–9. https://doi.org/10.3171/2019.1.JNS182769
34. Xu A, Bhatnagar J, Bednarz G, Niranjan A, Kondziolka D, Flickinger J, et al. Gamma Knife radiosurgery with CT image-based dose calculation. J Appl Clin Med Phys. 2015;16(6):119–29. https://doi.org/10.1120/jacmp.v16i6.5530
35. Tham BZ, Aleman D, Nordström H, Nygren N, Coolens C. Plan Assessment Metrics for Dose Painting in Stereotactic Radiosurgery. Adv Radiat Oncol. 2023;8(6):101281. https://doi.org/10.1016/j.adro.2023.101281
36. Jamovi - open statistical software for the desktop and cloud. (n.d.). Reference Source
37. Ikawa T, Kanayama N, Arita H, Ohira S, Takano K, Hirata T, et al. Linear accelerator-based stereotactic radiotherapy for brain metastases, including multiple and large lesions, carries a low incidence of acute toxicities: a retrospective analysis.

Radiat Oncol. 2023;18(1):1–9. https://doi.org/10.1186/s13014-023-02262-z
38. Wen N. A novel linear accelerator based stereotactic radiosurgery system. Imaging Med. 2015;7(1):45–7.
39. Chambrelant I, Jarnet D, Le Fèvre C, Kuntz L, Jacob J, Jenny C, et al. Comparative study of dynamic conformal arc therapy and volumetric modulated arc therapy for treating single brain metastases: A retrospective analysis of dosimetric and clinical outcomes. Phys Imaging Radiat Oncol. 2024;30:100591. https://doi.org/10.1016/j.phro.2024.100591.
40. Durmuş IF, Esitmez D, Arslan GI, Okumus A. Dosimetric Comparison of Three-Dimensional Conformal, Intensity-Modulated Radiotherapy, Volumetric Modulated Arc Therapy, and Dynamic Conformal Arc Therapy Techniques in Prophylactic Cranial Irradiation. Prog Med Phys. 2023;34(4):41–7. https://doi.org/10.14316/pmp.2023.34.4.41
41. Bortfeld T, Oelfke U, Nill S. What is the optimum leaf width of a multileaf collimator? Med Phys. 2000;27(11):2494–502. https://doi.org/10.1118/1.1319524
42. Kubo HD, Wilder RB, Pappas CTE. Impact of collimator leaf width on stereotactic radiosurgery and 3D conformal radiotherapy treatment plans. Int J Radiat Oncol Biol Phys. 1999;44(4):937–45. https://doi.org/10.1016/s0360-3016(99)00041-3
43. Fiveash JB, Murshed H, Duan J, Hyatt M, Caranto J, Bonner JA, et al. Effect of multileaf collimator leaf width on physical dose distributions in the treatment of CNS and head and neck neoplasms with intensity modulated radiation therapy. Med Phys. 2002;29(6):1116–9. https://doi.org/10.1118/1.1481515
44. Petrova D, Smickovska S, Lazarevska E. Conformity index and homogeneity index of the postoperative whole breast radiotherapy. Open Access Maced J Med Sci. 2017;5(6):736-9. https://doi.org/10.3889/oamjms.2017.161
45. Al-Rawi SAI, Abouelenein H, Nagdy MES EL, Alabdei HH, Sulaiman AA, Al-Nuaimi DS, et al. Assessment of dose gradient index variation during simultaneously integrated boost intensity-modulated radiation therapy for head and neck cancer patients. Precis Radiat Oncol. 2022;6(3):216–24. https://doi.org/10.1002/pro6.1166
46. Sung KH, Choi YE. Dose gradient curve: A new tool for evaluating dose gradient. PLoS One. 2018;13(4):e0196664. https://doi.org/10.1371/journal.pone.0196664
47. Shahban M, Rizwan MT, Nazia NS, Saeed UR, Humera M, Faheem M. Evaluation of intracranial stereotactic treatment plans: a comparison study of CyberKnife and TrueBeam systems. J Radiother Pract. 2024;23. https://doi.org/10.1017/S1460396924000104
48. Durmus IF, Okumus A, Pehlivan B, Topkan E. Dosimetric comparison of volumetric modulated arc therapy and dynamic conformal arc therapy techniques for radiosurgery of single brain metastasis. J Cancer Res. 2021. https://doi.org/10.4103/jcrt.JCRT_738_20
49. Asnaashari K, Chow JC, Heydarian M. Dosimetric comparison between two MLC systems commonly used for stereotactic radiosurgery and radiotherapy: A Monte Carlo and experimental study. Physica Medica. 2012;29(4):350–6. https://doi.org/10.1016/j.ejmp.2012.05.001