Dosimetric Comparison of Between Multileaf and Fixed Cone Collimator Plans with Cyberknife-M6 in the Benign Skull Base Tumors

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ABSTRACT

CyberKnife (CK) is a SRS technique that ensures highly conformal dose distrubutions using a linac based robotic arm and image guidance with real-time tumor tracking. We aimed to retrospectively evaluate the clinical benefit and dosimetric outcomes of MLC and fixed cone-plans. Eleven acoustic schwannoma and 20 glomus jugulare patients' plans were retrospectively re-planned and analyzed. Treatment time, homogenity index (HI), conformity index (CI) and gradient index (GI) for PTV, volumetric doses of brain and brainstem, cochlea, beams and monitor units (MUs) were compared between MLC and fixed collimator planning system. The cochlea dose was observed significantly decrease in MLC plans (p= 0.023). Brainstem maximum point dose and also V10 Gy and V15 Gy of brain were significantly lower in MLC plans (p= 0.021, p= 0.014, p= 0.000, retrospectively). MLC plans consist less nodes and segments in comparison to fixed plans, also has less MU and shorter deliver treatment time (p= 0.00). The average delivered MUs in MLC plans are lower by 45% (p= 0.000). We confirmed the feasibility of time delivery effiency and reduced delivered MU in MLC planning techniques. Our analysis revealed that MLC plans have almost equivalant treatment plans with the fixed ones. The most precious finding is the MLC plans obtained higher protection on critical structures and consistently showed better dose gradient fall which is important for toxicity and second malignancies.

Keywords: Radiation oncology , SRS, Cyberknife M6, Skull base tumors

INTRODUCTION

CyberKnife (CK) is a new SRS technique that ensures highly conformal dose distributions using a linear accelerator based robotic arm and image guidance equipped wıth tumor tracking feature utilized simultaneously with real time tracking at the time of treatment fraction. Tracking accuracy enables significant reduction of the planning target volume (PTV) margin and potentially better protection of the critical tissue due to rapid dose decrease at its edge.[1]

Technically, CK utilizing a 6-MV energy linear accelerator installed on a robotic arm that is able to deliver radiation in a non iso center non coplanar radiation beam arrangements. This advanced characteristic enables the achievement of multiple radiation plans with different qualities and different characteristics.[2] The newest CK-M6 system version contains a new format for the primary, secondary and tertiary collimators that gives advantage for a various range of non-coplanar beam orientations. Multileaf collimators (MLC) are alternatively can be exchanged between fixed and variable circular aperture collimator of this systems. Basically, MLC plans showed equivalent plan quality and significant fraction time reduction when compared to radiological control.[3]

Our objective was to evaluate retrospectively the clinical application and dosimetric results of MLC in comparison with fixed cone-based plans.

PATIENTS and METHODS

A total of 31 patients; 11 acoustic schwannoma and 20 glomus jugulare patients' plans were retrospectively re-planned and analyzed. Treatment was planned using Cyberknife M6 TM software version 2.0.0.1 planning system (Accuray Incorporated, Sunnyvale, CA, USA). A non-contrast CT scan simulations with 1 mm thickness, utilızed with axial T1 post gadolinium-enhanced 3D MRI fusion with same CT slice thickness without any skip. Gross target volume (GTV) was delineated wıth radiographic guidance of fused MRI series. Treatment time, monitor unit (MU), homogeneity index (HI) conformity index (CI) and gradient index (GI) for PTV, V15b Gy, V10b Gy and V5b Gy for the brain (b) V15 Gybs, V10bs Gy, V5bs, V2,5bs Gy for the brainstem (bs) and V15 Gyc, V10c Gy, V5c, V2,5c cochlea (c), number of beams and monitor units (MUs) were also evaluated in both MLC and fixed collimator plans. PTV was generated by adding three-dimensional 1.0-mm expanding safe margin for GTV. Total prescribed dose was 21-25 Gy in 3-5 fractions. The goal was to cover > 95% of minumum dose of PTV. To avoid dose spills, 3 or 4 rings shells were applied within conformal radius of 3-15 mm from the PTV. Dose prescription was to 80.7%-92.3% ± 0.66 isodose line for fixed and 80.5%-91.20% ± 0.74 isodose line for MLC plans.

The level of isodose lines conformality was evaluated using the dose conformity index of the Radiation Therapy Oncology Group (RTOG) definition; the ratio of the volume receiving the prescription dose or greater and the volume of the target 4.

Statistical Analysis

Statistical analysis was performed using SPSS version 20.0. Wilcoxon's signed rank test was applied for demonstrating the difference between both plannin techniques. Analysis of PTV and normal structure doses were evalutaed using Pearsons correlation test. P value of < 0.05 was accepted statiscally significant.

Ethical approval was obtained from Uludag University Faculty of Medicine Ethical Committe, (2011-KAEK 26/514, 27/06/2022).

RESULTS

Mean tumor volume was 2,9 cc, range between 0.29-8.67 cc. The median beams that were used for MLC and fixed plans were 21.5 (12-39±6.02) and 75.5 (36-206±44.7). The median collimator sizes were 13.75 (10-30±4.79 for MLC and 15 (10-25±15) fixed collimator planning techniques.

Uniform target coverage was provided equal in both techniques (> 95%) (Figure 1 and 2). Multileaf collimator plans showed worse CI (p= 0.01), but a better rapid gradient fall of (p= 0.03). Considering MLC plans utilize a lower number of nodes and segments in comparison to fixed plans; MU and fraction time were found significantly decreased

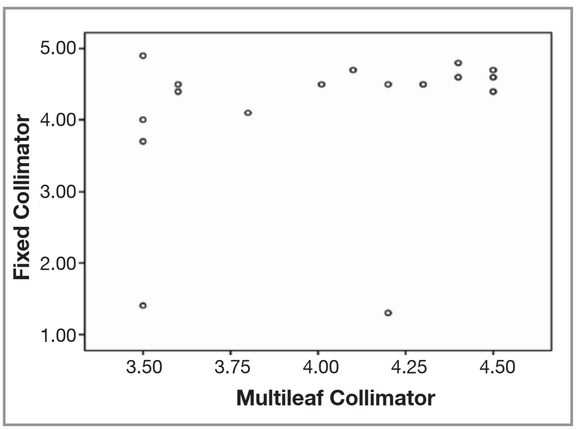

Figure 1. Comparison of CI for the fixed and MLC plans

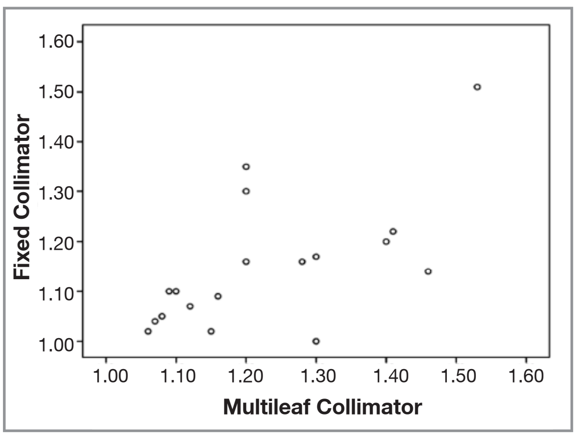

Figure 2. Comparison of GI for the fixed and MLC plans

Table 1. Comparison of dosimetric parameters between the fixed cone and MLC techniques

	MLC	(median)	FIXED	(median)	p
CI (min-max)	1.06-1.53	1.2	1.0-1.51	1.12	0.01
HI (min-max)	1.10-1.80	1.22	1.08-1.24	0.11	0.30
GI (min-max)	3.5-4.5	4.15	1.30-4.9	4.5	0.03
Prescribed dose	80.5%-91.20%	82.65%	80.7%-92.3%	83.45%	0.14
Treatment time (min-max)	11-18 min	14 min	16-40 min	23min	0.00
MU	3100-6410	4068.00	6200-20333	8792.00	0.00
Beams	12-39	21.7	36-206	88.3	0.00

(p= 0.00). The average delivered MUs in MLC plans are lower by 45% (p= 0.000). Dosimetric comparison between the fixed collimator and MLC plans is given Table 1.

We also evaluated critical organs tolerance doses for both collimator systems. Figure 3, demonstrates the dose distribution of the fixed and MLC treatment plans. The orange isodose line showa the total dose of 1800 cGy with 80% isodose line. Maximum (max) cochlea dose was constrained to 24 Gy, and 27.5 Gy, brainstem maximum dose was constrained 7.23 Gy and 6.5 Gy in 3 and 5 fractions, retrospectively. Maxiumum cochlea dose had been shown significantly lower in MLC plans in comparison to fixed plans (p= 0.023).

VmaxbsV10 Gybs, V15bs Gy were associated with decreased dose in MLC based plans (p= 0.021, p= 0.014, p= 0.000, respectively). V5bs, V2,5bs Gy doses did not show any differences between two plans. Comparison of dosimetric results with critical structures between the fixed cone and MLC plans were given in Table 2.

In our study, there is a relative relationship was observed between PTVcc and the volume of brain that received dose in each technique. A significant association between PTV (cc) and any volumetric dose of the brain was found statistically in both treatment plans. In regard to, brainstem dose was evidently correlated with PTVcc in both plans, the relavance of V15bsGy could not be demonstrated

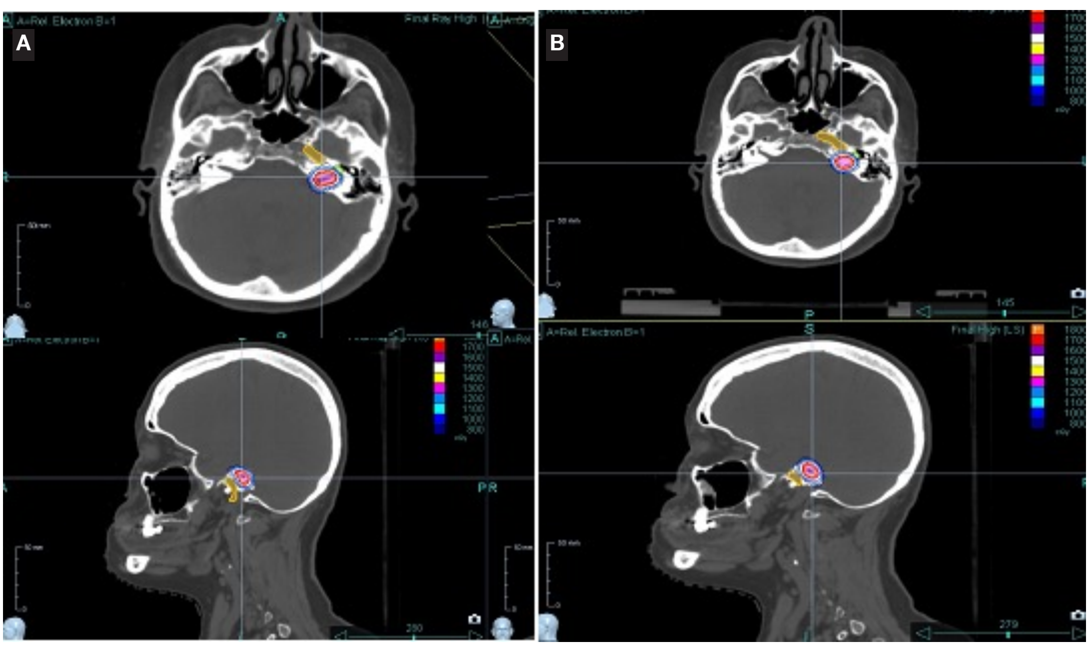

Figure 3. Comparison of the dose distributions of **(A)** fixed and **(B)** multileaf collimator plans for a selected case

Table 2. Comparison of critical structures between the fixed cone and MLC plans

Critical structures	Treatment technique (min-max±SD)				
	MLC	(median)	FIXED	(median)	p
Cochlea (cGy)	849-2235±78.07	1279	833-2263±87.21	1334	0.023
Brain stem max (cGy)	261-2453±166.74	875	11-2340±177.38	1550	0.021
BrainstemV2.5 Gy	0.08-23.93±1.55	6.95	0.14-30±1.89	3.75	0.230
BrainstemV5 Gy	0.0-2.76±4.05	1.93	0.0-20.32±4.87	2.5	0.140
Brainstem15 Gy	0.0-1.23±0.09	0.05	0.0-1.0±0.33	0.10	0.220
BrainV2.5 Gy	35.50-338.58±18.4	94.52	21.71-500.18±25.7	82.64	0.255
BrainV5 Gy	7.59-90.30±1	24.36	4.39-142.24±131.27	32.54	0.109
BrainV10 Gy	0.64-23.33±11.48	5.125	0.59-44.15±111.47	10.04	0.014
BrainV15 Gy	0.06-13±10.82	2.130	13-23.99±1.64	3.78	0.000

in MLC technique. In addition, a substantial intercourse was found between PTV (cc) and treatment time, beam number and MU only in MLC planning technique. With contrast to the results with MLC, treatment time, beam number and MU were shown to be independent factors from tumor volume in the fixed collimator plans. The impact of PTV (cc) on dosimetric parameters in both planning techniques were given in Table 3.

DISCUSSION

Developments in image guidance, advancement of dose delivery techniques, and hypofractionation radiation regimens, have led to more precise treatment. Image guidance procedures and using more beams prolonged the treatment time in the patients treated with stereotactic techniques including robotic radiosurgery system. There are limited studies were comparing CK-MLC and fixed plans in the literature regarding skull base tumors.

In the CK system radiation has tungsten cones, known as fixed and adjustable Iris collimators. Both collimator system with aperture diameters ranging from 5 to 60 mm at a SAD of 80 cm. Fixed circular collimators have very low collimator transmission, sharp penumbrae and adapted field size reproducibility.[3] These features are highly important for sparing adjacent normal tissues in the patients treated with radiosurgery techniques.

In 2015 CK M6 series was updated with new facilities. Recent technological improvements 3 like adding multi leaf collimator (MLC) gives to opportunity treat irregular and large volume shaped targets with similar dosimetric quality, less beams and MU comparing to fixed or variable modalities. MLC has leaf with width of 3.85 mm and the maximum field size is 11.5 x 10.1 cm^2 in 80 cm SAD. One of the major advantage of MLC is reduced treatment time with the patients with large tumor. In spite of these advantages, the dosimetric gain and clinical applications of MLC have not been extensively studied and clarified yet.

Radiosurgery involves submilimetric geometric beam delivery accuracy and steep dose gradient. Generally, a single collimator is used for all beams. In previous literature, to provide more accurate step dose gradient with CK system, up to three

Table 3. Impact of tumor size on dosimetric parameters according to planning techniques

PTV (cc)	CI	GI	HI	V2.5Gy brain	V5Gy brain	V10Gy brain	V15Gy brain	V2.5Gy brainstem	V5Gy brainstem	V15Gy	Time	Beam	MU
MLC	0.22	0.05	0.94	0.000	0.008	0.008	0.031	0.04	0.07	0.27	0.000	0.000	0.00
Fixed	0.54	0.74	0.99	0.000	0.000	0.001	0.001	0.000	0.003	0.013	0.164	0.35	0.63

fixed collimators combinations have been used in a single treatment plan. Small collimator technique yields high dose compatibility without compromising the tumor volume and large collimator technique reduces the total number of monitoring units and treatment beams.[4] Combining of two collimators are also applicable for iris and fixed collimator planning for sharp penumbra.[5] A recent study including lung cancer patients, has demonstrated that combining two collimators decreased total MU by an average of 31% (range, 4-56%) in comparison with conventional treatment plans obtained using a single field size.[6]

Newly CK MLC system, named InciseTM, generates better dose distributions in a single plan and time efficient treatment especially for the large sized tumors compared to the fixed- collimator plans.[7] This technique seems to be more efficient in non coplanar beam delivery than gantry-based modalities, because manual couch interventions would not be necessary as in fixed techniques. Treatment plans typically includes 60 node positions, 125 beams, and 35.000 MUs. The most important feature of multileaf collimator MLC is flexible field shaping not only circular, ensuring more efficient treatment plans. It allows for three dimensional conformal radiotherapy (3D-CRT) for high precison coverage without using unnecessary large number of circular beams thereby reducing the number of beams and MUs.

In contradiction, Jang et al.[1] demonstrated that the conformity index of MLC-based plans were slightly higher than those of the fixed/IRIS-based plans (1.37 vs. 1.28) regardless of volume of target, number of targets, and complexity of the target shape. In spite of target volume coverage was likely similar in both planning techniques MLC based plans has time reducing efficacy. They also stated dose conformity with MLC-based plans for targets adjusted critical organs was inferior comparing to fixed plans in contrast to our study.

One of the the most significant advantages of MLC based plans being superior to the fixed/ IRIS-based plans is decreased time delivery. Total treatment time is primarily related on the total number of beams rather than the total number of MUs. It was clearly concluded that MU in MLC treatment plans was considerably reduced by > 50% compared with the cone/Iris-based plans 1 In similar, our results supported that MLC plans are much more time efficient and this could be related with the less beams numbers as in Jang et. al's study.[1]

McGuinness et al.[8] also determined the clinical advantages of the InCise MLC in the treatment of brain and prostate cancer patients. The authors reported that the CI in the MLC-based plans were comparable to those of circular collimators, and delivery time as shorten almost by 50%. They also observed decreased dose to critical organs for the MLC-based plans in comparison to fixed ones. In compatible with, we demonstrated MLC plans superior sparing critical organs and consistently provided better CI, however, with worse GI in our study.

In the study of Kim N, et. al, they demonstrated high quality plans with MLC with a better HI and GI. CK-MLC plans showed improvement for the gradient index ($p< 0.001$). There was not a major difference was shown in regard to CI ($p= 0.16$) but the median fraction delivery time was significantly reduced by 30% (to 34 vs 48 min; $p< 0.001$. In conclusion, CK-MLC showed high likely an equivalent treatment plan with significantly reduced time compared with CK-fixed, even with larger tumor volumes.[9]

CK-MLC plans are found successful to treat larger PTV volumes without affecting either CI or PTV coverage with comprehensive dose homogeneity and rapid fall off. MLC based treatment also showed dosimetric advantages even with larger and irregular-shaped lesions as in our study. Kathriarachchi et al. also demonstrated CK-M6 showed comparable conformity, target coverage, critical tissue sparing, tumor control probability with substantially shortened treatment time in prostate radiotherapy.[10]

Conclusion

MLC plans demonstrated highly equivalent isodose lines compared to fixed based plans and provided significantly better dose gradient fall off in the our study. MLC type plans provide less delivery time and reduced MU with high quality conformal treatment especially for the irregular and large sized tumor. As a clinical point of view, these features promise less second malignancies and unnecessary dose distrubution on normal tissues. CK-MLC treatment could be the preferred choice of treatment both in technically and the clinically.

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