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Dosimetric comparison of VMAT and CyberKnife plans in intracranial lesions

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ABSTRACT

The aim of our study was the dosimetric and physical evaluation as a retrospectively of the CyberKnife (CK) and Volumetric Arc Therapy (VMAT) treatment plans for eighteen intracranial targets which are fourteen of them are single lesion and four of them are double lesion. Target volume and critic organ doses are compared in CyberKnife and VMAT plans. Conformity and homogeneity index values are compared in target volume and more homogeneous plans are obtained in VMAT plans. Better results are obtained for Monitor Unit values in VMAT plans since small collimators are used with plans which made by CyberKnife. Also, better results are obtained in low dose values that are taken from brain thanks to non-coplanar areas with CyberKnife. Critic organs which have high dose gradient has lower mean dose values in CyberKnife plans. Better results are obtained on critic organ maximum dose values in VMAT plans. There are dosimetric and physical differences in RadioSurgery practices with CyberKnife and VMAT treatment techniques.

Keywords: Intrakranial tumor, CyberKnife SRT, VMAT SRT

INTRODUCTION

In 1951, Dr. Lars Leksell's description of Stereotactic Radiosurgery (SRS) as an implementing high radiation doses at single fraction with stereotactic technique [1]. Conformal dose distribution is obtained with SRS by implementing multiple beams which go toward to target in small area sizes with non-coplanar technique. Improvements in image guide systems provide increasing geometric accuracy so improvements repeatability of treatment is easier. Furthermore, implementing high radiation doses at several fractions to increase normal tissue repair is identified that Stereotactic Radiation Therapy (SRT). Limitation of dose at normal tissue depends on geometric accuracy and accurate repeatability of treatment. Protection of normal tissue increases even more with non-coplanar irradiation by providing rapid decrease of dose.

CyberKnife system (Accuray, Inc, Sunnyvale, CA, USA) is one of the most improved example in SRS/SRT implementations. It is a treatment device that can be used for very small field size, it has radiation doses per fraction in the non-coplanar and also it has a multiple point imaging-guided therapy. The device provide targeting LINAC with relating X-ray and CT images during treatment and it treats as non-coplanar by high sensitivity [2],[3],[4].

IMRT is the most improved form of three dimensional conformal radiotherapy. When intended dose distribution is obtained at concave shaped target by using different intensity beams, doses of critic organs around tumor are held identified tolerance values. Base of IMRT is Multi Leaf Collimator (MLC) system that arranges intensity of dose. Multi Leaf Collimator system provides to be beamed just tumor area and protecting necessary areas but it requires detailed quality control program in planning as well as irradiation because of complexity of technique [5].

Volumetric Modulated Arc Therapy (VMAT) is a new IMRT technique which dose rate, gantry speed and MLC speed changes dynamically during irradiation. When static areas are used in IMRT, rotational geometric areas are used in VMAT. First time, this technique is developed for Varian Linear accelerator by Otto with the name "RapidArc" [6]. There are improved control points throughout rotational areas in VMAT plans. Gantry speed, dose rate, gantry position and cumulative MU are controlled in every control points. It controls association between gantry movement, gantry position and implementing MU. The other control mechanism is MLC position during dynamic irradiation. It controls relation with MLC movements in every gantry angle [4],[7].

1. MATERIAL AND METHOD

Cyberknife System: The Cyberknife system implements radiation by using isocentric or non-isocentric techniques to a target that is determined as 3D coordinate system with imaging guide systems in high accuracy. In SRS/SRT/SBRT, treatment is implement without stereotactic frame under the guidance of image.

Cyberknife has a twelve different area sized collimators that are between 0.5 cm and 6 cm. High radiation doses are implemented in small sized areas. The device at X band has a compact linear accelerator that can reach 800 cGy/min dose rate and produce X-Rays in 6 MV energy. Robotic arm of Cyberknife has better mechanic accuracy than 0.12 mm [3].

Compact linear accelerator design of the system removes deflector magnet need and the system has not beam flatner filter. Cyberknife system provides image guided treatment to patient with X-ray tubes which are mounted on roof and amorph silicon side semiconductor which are on floor. Thus, Cyberknife treatment device can be used not just in intracranial lesions and also can be used for lesions in anywhere of the body.

Intracranial and cervical lesions up to the third spinal 6D skull tracking algorithm has been developed to track. This algorithm is used for the lesions that does not move as skull. This method calculates the deviation amounts according to high contrast bone elements in skull by comparing X-ray images and Digital Reconstructed Radiograph (DRR) that is obtained CT images. Planar (X,Y,Z) and rational (Pitch, Roll,Yaw) deviation amounts in X-ray images are calculated by referencing DRR images and treatments are administered by editing with robotic arm and Robocouch® table.

Clinac DHX Linear Accelarator: Clinac DHX RapidArc (Varian Medical Systems, Palo Alto, CA, ABD) linear accelerator has 6MV and 15MV photon and 6, 9, 12, 16 and 20 MeV electron energies. The device can do dynamic IMRT, static IMRT and VMAT and has 120 MLC leafs. Thickness of MLC is 0.5 cm in center and it is 1 cm wide after 20x20cm2 MLC is independent from jaw and in this way more successfull IMRT and VMAT plans are enable. In Varian Clinac DHX device, gantry speed is between 0.5 and 4.8 degree/sec, dose rate is between 0 and 600 MU/min, MLC speed is between 0 and 2.5 cm/s (5 mm/degree) implemented dose in every degree is between 0.2 and 20 MU/degree is implemented during dynamic irradiation.

VMAT and CK plans: 18 patients who have intracranial lesion and who had been treated with Cyberknife device were choosen for this study. Fourteen of these patients has single lesion and four of them has double lesions. CT images were taken with 1 mm slice for eighteen intracranial patient. Clinical Target volumes (CTV) and risky organ volumes are contoured in Multiplan 4.5.3 (Accuray, Inc., Sunnyvale, CA, USA) treatment planning system (TPS) by fusion with performed images MR. Planning Target Volume (PTV) was generated by adding CTV 1-2mm margin. Treatment plans were obtained by using Equivalent Path Length (EPL)-based correction Ray-Tracing dose calculation algorithm and non-isocentric technique in CyberKnife Multiplan TPS .Table 1 shows general features of intracranial patient that is treated with CK.

Table 1: General properties of 18 intracranial patient treated with CK

Patient	Lesion	Volume (mL)		Collimator Diameter (mm)		Reference isodose line	Dose (cGy)
		PTV1	**PTV2**	**PTV1**	**PTV2**	**%**	**cGy**
1	Single	18,90		10-20-25		85	3000
2	Single	10,10		10-15-20		86	3000
3	Single	7,55		10-35		84	2100
4	Single	2,06		7.5-10-15		87	2400
5	Single	3,66		7.5-12.5-15		88	880
6	Single	37,97		20-30-35		83	3000
7	Single	2,48		10-15		88	2400
8	Single	2,56		7.5-10-12.5		87	870
9	Single	1,89		7.5-12.5		88	2400
10	Single	2,52		10-12,5		85	2100
11	Single	0,89		7.5-10-12.5		87	870
12	Single	2,06		7.5-10-15		89	2400
13	Single	7,50		15-20		86	1400
14	Single	7,07		10-15-25		83	2400
15	Double	1,81	0,46	10-15	5-7.5	83	1400
16	Double	4,17	7,37	10-15	10-20	86	2100
17	Double	17,64	7,50	12.5-25	12.5-20	83	1400
18	Double	7,07	14,97	10-15-25	15-25	84	2400

Same CTV and organ at risk volumes were contoured in Eclipse 8.9.17 (Palo Alto, CA, ABD) TPS for VMAT plans. VMAT plans were made with isosentric technique by using Analytical Anisotropic Algorithm (AAA) dose calculation algorithm in Eclipse TPS at 6MV energy. Two coplanar arcs with 360^0 were used by choosing that maximum dose rate is 600 MU/min and angle of collimator is $\pm 45^0$ in VMAT plans.

In CK and VMAT plans, at least 95% of target volume was token prescription dose. Dose restrictions of National Comprehensive Cancer Network (NCCN) were referenced for critic organ doses.

$PTV_{minimum}$, $PTV_{maximum}$ and PTV_{mean} doses were examined in VMAT and CK plans separately for 14 single and 4 double lesion. Mean and maximum doses of brain, optic nerves, lenses, chiasma and brainstem were compared as a critical organs. In addition to this, volumes of brain tissue that are took dose at V5, V10 and V20 were examined. Doses are give as a dose (cGy) ± standard deviation.

Values of homogeneity index (HI) for 18 intracranial patient and values of conformity index (CI) for 14 single lesion are calculated below methods at PTV and is obtained thorough the equation 1,2

$$CI=\frac{TIV}{HIV} \tag{1}$$

$$HI=\frac{Dmax}{Dx} \tag{2}$$

In this methods, shows; TIV: defined isodose volume, HIV: covering the target volume isodose, Dmax: maximum dose and Dx: prescription dose in target.

2. STATICTIC

Wilcoxon signed rank test was used to test statistically significance of had been obtained differences between dose distributions with CK and VMAT plans. $p \leq 0.05$ significance limit is accepted in all statistic analyses.

3. RESULT AND DISCUSSION

Figure 1, It shows the CK and the same tumor volume for VMAT dose distribution

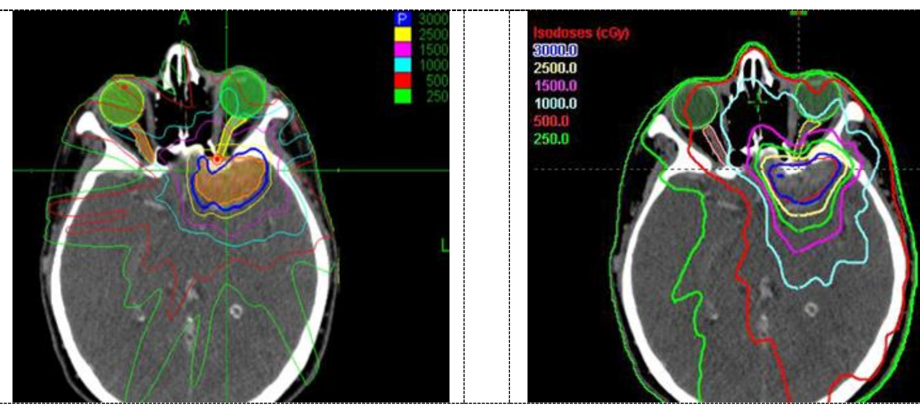

Figure 1. *CK (left) and VMAT (right) dose distribution*

$PTV_{minimum}$, PTV_{mean} ve $PTV_{maximum}$ doses were compared for 14 single and 4 double lesion from VMAT and CK plans. Table 2 shows PTV doses for CK and VMAT. $PTV_{minimum}$ doses were found similar for both irradiations technical. PTV_{mean} and $PTV_{maximum}$ doses are higher in CK at single lesion irradiations. (p=0,01)

Table 2: PTV doses with single and double lesions. The numbers in parentheses indicate the number of patients.

		CK	VMAT	P
Single Lesion PTV (14)	Minimum	2046±573	2087±561	0,84
	Mean	2400±681	2268±633	0,01
	Maximum	2581±751	2365±669	0,01
Double Lesion PTV1(4)	Minimum	1748±398	1769±377	0,46
	Mean	2137±429	1878±431	0,68
	Maximum	2167±563	1939±447	0,68
Double Lesion PTV2(4)	Minimum	1733±405	1807±389	0,68
	Mean	2006±476	1882±415	0,68
	Maximum	2163±491	1950±452	0,68

Figure 2 shows that CI values in VMAT and CK plans for 14 single lesion. CI results were obtained lower in VMAT plans. When results of CI were average 1.21±0.05, its results were average 1.05±0.07 in VMAT plans. ($p=0,03$)

Figure 3 shows HI values in VMAT and CK plans for 18 patients. When HI was average 1.16±0.02 in CK plans, it was average 1.05±0.02 in VMAT plans. ($p\leq0,001$)

In VMAT plans, better CI and HI values were obtained. However, CI and HI values can be accepted clinically in all prepared plans which are prepared with CK and VMAT techniques.

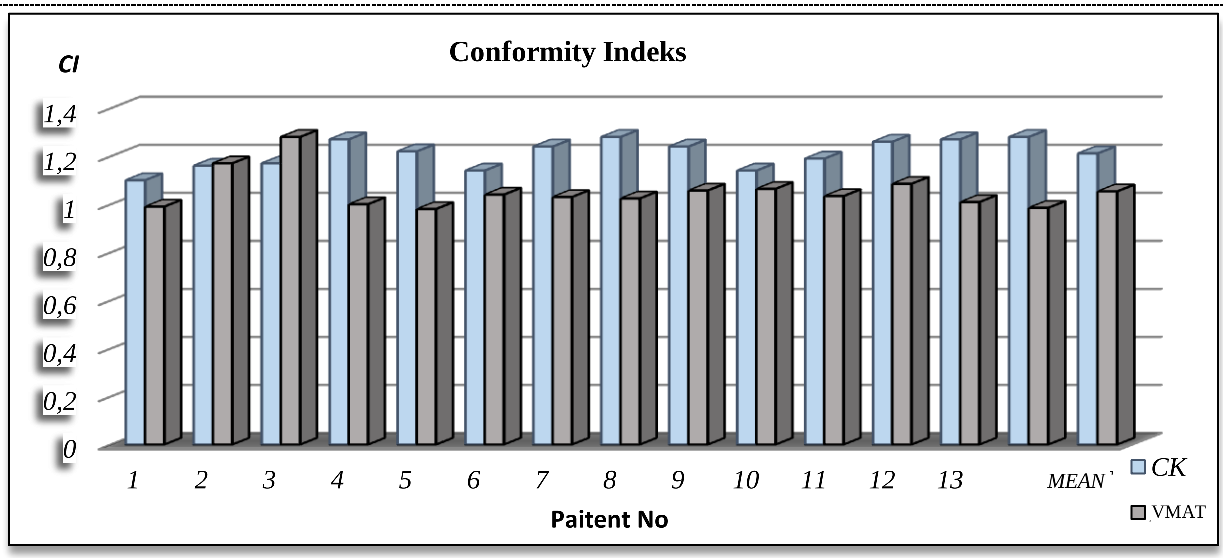

Figure 2: *CK and VMAT conformity index (CI) values for single lesions.*

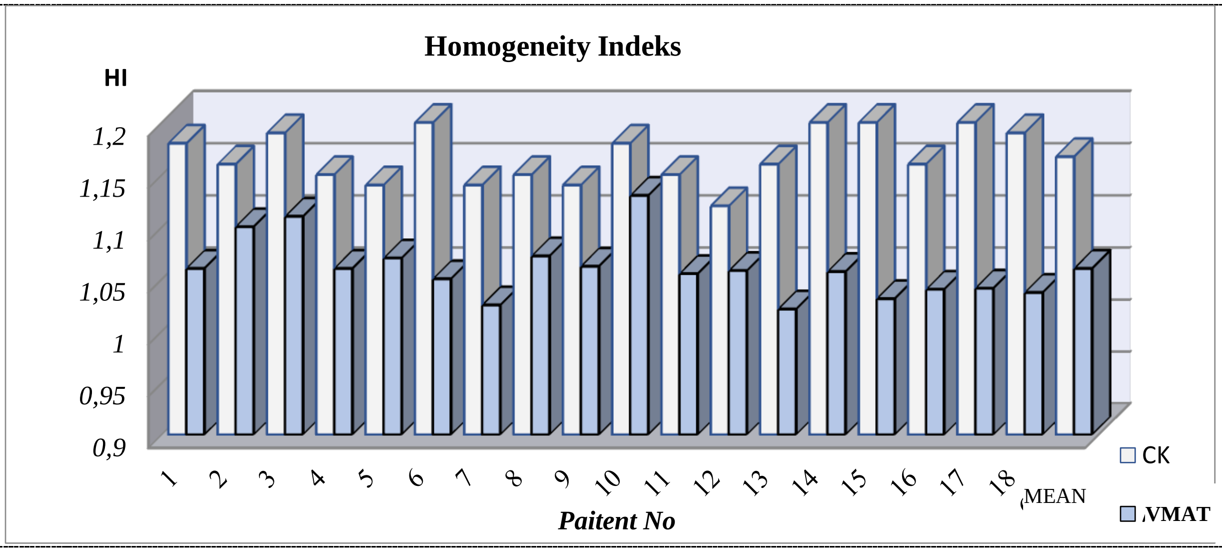

Figure 3: *CK and VMAT homogeneity index (HI) values for single and double lesions*

When average MU was 17224.15±10024.88 in CK plans, it was found 5527± 2759.67 in VMAT plans for 18 patients. When critic organ doses were compared, mean doses of all critic organs were found lower with CK. (TABLE 3) Maximum dose in brain was found significantly higher with CK (p≤0.001). Since dose is defined in lower reference isodose lines to provide dose coverage in PTV, Maximum dose value in brain tissue was found higher than VMAT plans in PTV.

Table 3: Critic organ doses

		CK	VMAT	P
Brain	Mean	177±133	210±159	0,133
	Maximum	2467±692	2275±634	0,0000
	V5	8,14±7,60	13,10±12,70	0,023
	V10	3,21 ±2,92	4,90± 4,74	0,006
	V20	1,51± 1,49	1,71± 1,54	0,113
R Optic Nerve	Mean	126±314	132±218	0,58
	Maximum	244±494	198±321	0,777
L Optic Nerve	Mean	59±99	190±382	0,001
	Maximum	152±244	319±687	0,16
Optic Chiasm	Mean	220±501	243±454	0,12
	Maximum	383±838	396±807	0,215
Brainstem	Mean	132±132	163±141	0,267
	Maximum	579±703	703±722	0,39
R lens	Mean	21±50	61±82	0,01
	Maximum	37±71	82±112	0,07
L lens	Mean	25±66	66±91	0,00
	Maximum	40±84	82±107	0,02

Obtained V5Gy, V10Gy and V20Gy volumes with CK are found lower than VMAT plans for 18 patient. (Fig 4)

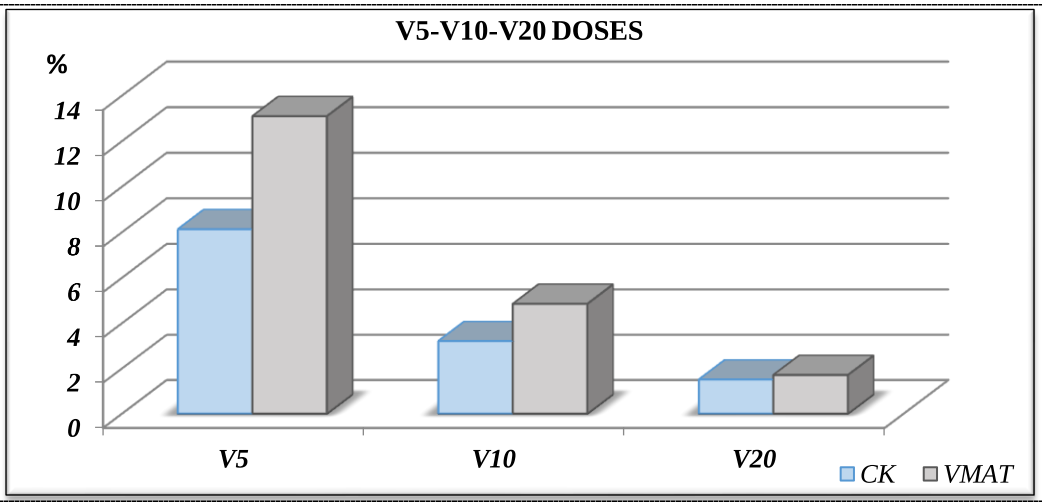

Figure 4: *Obtained V5, V10, V20 doses for brain with CK and VMAT*

When V5 dose was obtained average 8.13±7.6 in CK plans, it was obtained average 13.09±12.6 in VMAT plans for V5 (p=0,023). When dose was average 3.21±2.9 in CK plans, it was found average 4.85±4.7 in VMAT plans for V10 (p=0.006). When dose was average 1.51±1.4 in CK plans, it was found average 1.70±1.4 in VMAT plans for V20 (p=0.113).

V5 and V10 values were found significantly lower with CK especially in brain. Tissue volume that took low dose decreased by providing fast dose gradient with non-coplanar technique in CK. Since irradiations are made in 360^0 angle in VMAT plans by using rotational geometry areas. Volumes that took low dose were found higher.

While comparing prostate IMRT and CK plans[9], [10], [11]; we have managed to protect critical organ by fast decreasing doses. They declare that CK treatment is better than IMRT in critic organ doses especially areas with high doses. Homogeneity index value was better with IMRT. They found that heterogeneity of dose is lower at target volume in CK plans because of the features of the system. While CI value is beter in IMRT plan in Ceylan et al. [9], in Sabbir Hossaain et al. [10] and Mahada et al. [11] get better results with CK.

Lo [12] compares dosimetric treatment plans that had been prepared with RapidArc and CK treatment devices for brain lesions. Plans were prepared with CK non-isocentric technigue. Isocentric plans were prepared in RapidArc with 2.5 mm HD MLC. 50% of volume prescription dose and all of prescription dose was compared and they found about 70% higher in RapidArc plans. Dose coverage and minimum dose values were found similar in target. Dose values out 2 cm of target is found in RapidArc 45% higher than CK. As a result, they argued that decrease of dose is faster in CK and brainstem and cochlea doses are lower.

4. CONCLUSION

Plans that are made with CK and VMAT techniques can be implemented clinically but there are dosimetric differences between two techniques. When treatment is done with two 360^0 rotational area of VMAT plans, MUs are lower in VMAT plans because treatment is a multi-point with small collimators in CK .Change of the dose gradient are higher in CK plans than VMAT. When more homogeneous and conformal dose distribution are obtained in target with VMAT, Critic organs are protected better in CK.

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