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Dosimetric Comparisons of Single Arc, Double Arc VMAT, and Dynamic Multi Leaf Collimator Techniques in Stereotactic Radiosurgery for Brain Lesions

Yelda Elcim and Bora Uysal*

Department of Radiation Oncology; University of Health Sciences, Gulhane Medical Faculty, Ankara, Turkey

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Corresponding author: Bora Uysal, Department of Radiation Oncology, University of Health Sciences, Gulhane Medical Faculty, Ankara, Turkey, E-mail: drborauysal@windowslive.com

Abstract

Objective: This study evaluates the dosimetric performance of single arc (S-Arc) and double arc (D-Arc) Volumetric Arc Therapy (VMAT) techniques versus dynamic Multi Leaf Collimator (dMLC) in stereotactic radiosurgery (SRS) for vestibular schwannoma (VS), cavernoma (CA), and brain metastases (BM).

Materials and Methods: PTV contouring was performed for PTV-VS, PTV-CA, and PTV-BM using the Rando phantom's brain. Dose distributions were generated with S-Arc, D-Arc VMAT, and dMLC by the Monaco v.5.10, planning 12 Gy for PTV-VS, 14 Gy for PTV-CA, and 18 Gy for PTV-BM. Analyses included dose-volume histograms and statistical dose metrics, focusing on monitor unit values and treatment durations.

Results: For PTV-VS, no significant differences were observed in dose coverage, homogeneity, or effective dose among techniques. For PTV-CA, S-Arc and D-Arc showed similar coverage, while dMLC had a 1.5% decrease in coverage. In PTV-BM, D95 doses were 16 Gy for S-Arc and D-Arc and 17 Gy for dMLC, with effective doses consistent at 18 Gy. Maximum brainstem doses were 1269.5 cGy (S-Arc), 1291.1 cGy (D-Arc), and 1362.5 cGy (dMLC). D-Arc plans had 5.0%, 9.4%, and 22.2% increased MU for PTV-VS, PTV-CA, and PTV-BM compared to S-Arc, while dMLC showed differences of -0.7%, 9.4%, and 8.4% in MU compared to D-Arc.

Conclusion: For small PTVs, no significant differences exist among S-Arc, D-Arc, and dMLC. However, for larger volumes like BM, dMLC offers improved dose distributions at the cost of increased MU and treatment time. In clinics, preferences should be made between these treatment planning techniques considering the number of patients.

Keywords: Dose comparison; VMAT; DMLC; Stereotactic radiosurgery (SRS)

Abbreviations: SRS: Stereotactic radiosurgery; VS: Vestibular schwannoma; BM: Brain metastases; CA: Cavernoma; OS: Overall survival; VS: Vestibular schwannoma; ICM's: Intracranial cavernous malformations; DMLC: Dynamic multi leaf collimator; MC: Monte Carlo

Introduction

Stereotactic radiotherapy (SRT) is a treatment modality for Vestibular schwannoma (VS), cavernoma (CA) and brain metastases (BM) in the brain [1-6]. Stereotactic radiotherapy (SRT) is an essential treatment modality for brain metastases [7,8]. SRS is a high-precision technique that delivers a significant dose of radiation to a localized volume of an organ while minimizing radiation to healthy tissue surrounding it [9]. Local treatment options for brain metastases have improved greatly over the past time. Many randomized studies have established stereotactic radiosurgery (SRS) to achieve local control in a limited number of brain metastases. Although the addition of whole brain radiotherapy to other local treatments (Surgery and SRS) reduces the risk of distant intracranial recurrence, it does not improve overall survival (OS) and is associated with a decrease in neurocognitive functions that affect quality of life [10-14]. Therefore, recent studies have avoided whole brain radiotherapy for patients with multiple brain metastases. In the study conducted by Yamamoto et al., patients with 5-10 brain metastases were compared with patients with a more limited number of brain metastases. It was determined that survival was similar in patients with 5-10 brain metastases. It was evaluated that SRS, as suggested by similar studies, could be a suitable alternative even for patients with a larger number of BMs. However, distant intracranial recurrences after SRS should not be ignored and patients should be followed closely [15]. Surgery is the principal treatment for safely accessible hemorrhagic and symptomatic cavernous malformations. Nevertheless, the role of linear accelerator (LINAC)-based stereotactic radiosurgery (SRS) in the management of high-risk, symptomatic cavernoma lesions warrants further refinement [16].

Intracranial cavernous malformations (ICMs) are benign vascular lesions with an annual bleeding prevalence of 0.15%-0.44% [17]. These are considered slow-flow malformations of dilated blood vessels that have a berry-like appearance [18]. Most lesions are detected incidentally, as they often present with bleeding, seizures, or focal neurological deficits [19]. The estimated annual hemorrhage rate in person-years is slightly higher in brainstem ICM than in non-brainstem regions; bleeding recurrence rates are similar. Multiple lesions are usually detected sporadically, with familial syndromes occurring. Resection is the preferred method for accessible, symptomatic lesions located in prominent areas. The overall morbidity reported for resection is high, 7-9% in deep-seated cases and 35-50% in brainstem cavernomas [20-21]. At this point, the benefits of stereotactic radiosurgery are undeniable. Stereotactic radiosurgery (SRS) represents a reasonable treatment option for hemorrhagic and symptomatic lesions, especially those located in areas at high risk of surgical morbidity [22-23]. Suitable patients should receive a single fraction of SRS with prescription doses of 11-13 Gy. Vestibular schwannoma (VS), formerly referred to as acoustic neuroma, is one of the common benign intracranial tumors with rising incidence due to improved and more frequent neuroimaging. RT has traditionally served as a viable treatment modality for VS management and radiosurgical applications in the forms of single fraction Stereotactic Radiosurgery (SRS) or Fractionated Stereotactic Radiotherapy (FSRT) have been utilized for treatment of patients [24]. This has led to a treatment modality pursuing a lower dose of single-fraction radiosurgery (12-13 Gy) or fractionated stereotactic radiotherapy. The results of tumor control and complication were compared for the 12-13 Gy SRS and the SRT techniques [25]. Vestibular schwannoma (VS) is the most common tumor of the cerebellopontine angle [17]. Its annual incidence is 3-4 per 100,000 people. [18]. VS is a benign, slow-growing nerve sheath tumor. Although annual growth rates vary, it is estimated to be around 2.9 +/− 1.2 mm per year. Common symptoms include hearing impairment (in 90% of cases), tinnitus, and vestibular disorders. Treatment options include surgery and stereotactic radiosurgery (SRS). SRS is a suitable technique with well-established long-term results for tumors up to approximately 3 cm in diameter (KOOS I, KOOS II). Although no randomized trials have compared SRS with microsurgery, numerous studies suggest that SRS provides local control similar to surgery and hearing preservation rates appear to be more favorable [26-31].

Materials and Methods

This study was performed by obtaining images of the Rando Phantom with a image thickness of 2 mm on a Toshiba Aquilion LB CT (Tokyo, Japan) used for CT simulation in the Radiation Oncology Clinic of Gulhane Training and Research Hospital. On the obtained Rando phantom images, PTVs with volumes of 0.464 cc, 0.949 cc and 2.859 cc were contoured with the Monaco contouring system to represent treatment plan structures PTV-VS, PTV-CA and PTV-BM, respectively. The dose distributions in the treatment plans were generated with Monaco v.5.10 TPS (Elekta, UK) using Monte Carlo (MC) algorithm with volumetric modulated arc therapy (VMAT) treatment technique with 6 MV photon energy in Elekta Infinty linear accelerator (Elekta, Crawley, UK) with single arc (S-Arc) and double arc (D-Arc) rotation and dynamic multi leaf colimator (dMLC) techniques. Treatment plans were made for PTV-VS, PTV-CA and PTV-BM with 12 Gy, 14 Gy and 18 Gy doses in a single fraction, respectively, and distributions were obtained. In all plans, the isocenter was placed at the geometric center of the PTVs. Distributions were calculated using the 2 mm grid size, and an MC dose calculation uncertainty of 1% per calculation was used. All treatment plans were generated to cover the PTV with 95% isodose curve and no hot point dose more than 107%. However, since the PTV-BM is located next to the brainstem critical organ, the brainstem tolerance dose is limited to a maximum of 15 Gy. Hence there were losses in PTV-BM dose coverage. Figures 1-3 show single-arc, double-arc VMAT and dMLC planning in the transverse section for PTV-VS, PTV-CA and PTV-BM, respectively. The dose volume histograms (DVHs) of the dose distributions obtained for PTV-VS, PTV-CA and PTV-BM are given in Figures 1-3, respectively. According to these DVHs and plan statistics, the values in the Tables 1-3 were obtained.

Table 1: Dose Coverage, Homogeneity and Effective Doses for PTV-VS.

	Coverage (cGy)		Homogenity (cGy)			Effective Dose (cGy)	
PTV-VS	D95	D98	D20	D10	D2	Dmean	D50
S-Arc	1247,0	1232,9	1312,3	1323,3	1347,3	1289,5	1289,8
D-Arc	1249,3	1233,7	1311,8	1321,3	1321,3	1290,8	1291,8
dMLC	1204	1179,9	1294,7	1309,5	1309,3	1268,4	1271,8

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Table 2: Dose Coverage, Homogeneity and Effective Doses for PTV-CA

	Coverage (cGy)		Homogenity (cGy)			Effective Dose (cGy)	
PTV-CA	D95	D98	D20	D10	D2	Dmean	D50
S-Arc	1449,5	1440,6	1505,3	1513,4	1548,8	1489,3	1491,2
D-Arc	1409,0	1392,3	1518,3	1528,7	1538,0	1479,2	1486,3
dMLC	1412,5	1351,6	1461,7	1461,2	1483,0	1443,0	1446,0

Table 3: Dose Coverage, Homogeneity and Effective Doses for PTV-BM.

	Coverage (cGy)		Homogenity (cGy)			Effective Dose (cGy)	
PTV-BM	D95	D98	D20	D10	D2	Dmean	D50
S-Arc	1613,3	1504,1	1916,3	1932,0	1949,1	1841,9	1870,0
D-Arc	1609,8	1513,0	1908,5	1924,1	1947,4	1836,8	1867,2
dMLC	1699,7	1608,8	1905,8	1919,4	1947,6	1863,2	1884,0

Table 4: Treatment MU values for PTV-VS, PTV-CA and PTV-BM.

	MU		
	PTV-VS	PTV-CA	PTV-BM
S-Arc	2220,37	3137,69	4040,88
D-Arc	2332,17	3243,93	4940,62
dMLC	2315,6	3548,26	5354,7

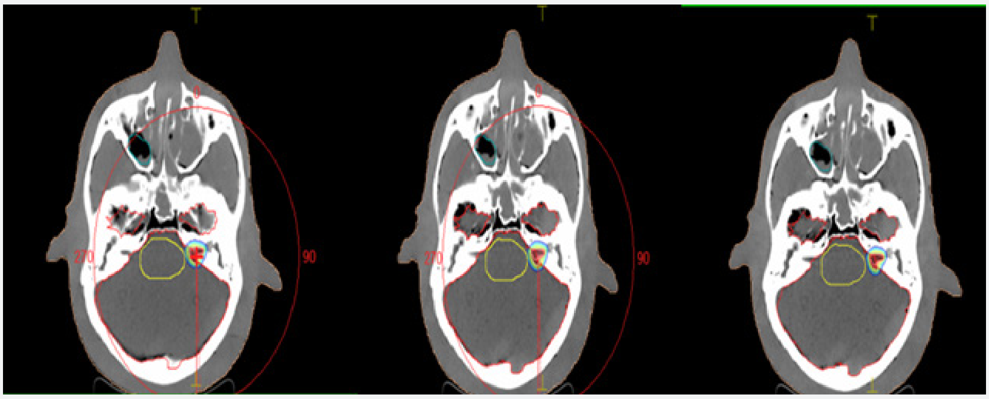

Figure 1: S-Arc, D-Arc VMAT and dMLC planning transverse sections for PTV-VS.

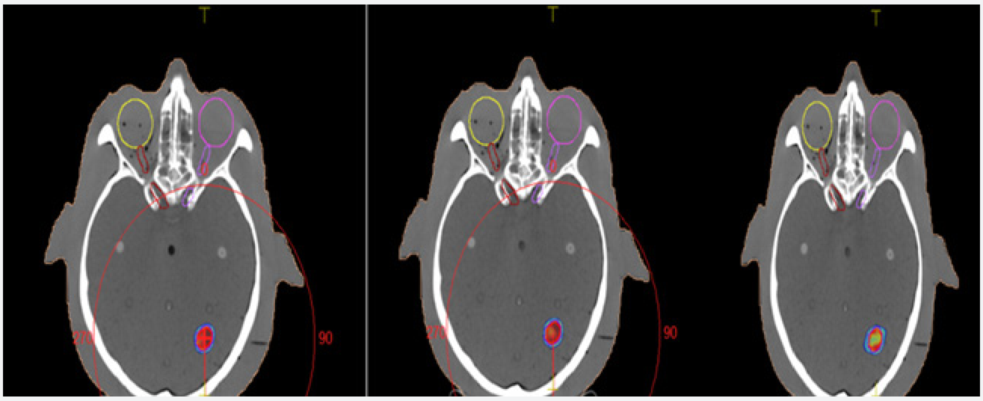

Figure 2: S-Arc, D-Arc VMAT and dMLC planning transverse sections for PTV-CA.

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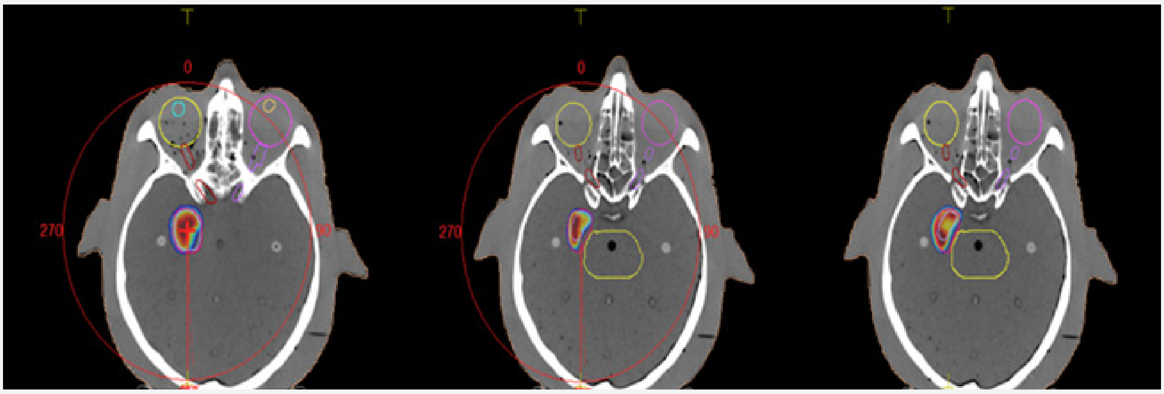

Figure 3: S-Arc, D-Arc VMAT and dMLC planning transverse sections for PTV-BM.

Results

Treatment plan dose distribution results with 12 Gy/1 fraction for PTV-VS were evaluated. Accordingly, we compared the plan techniques from the dose distributions obtained for PTV-VS. As seen in Table 1, there was no significant difference between the techniques in terms of dose coverage, homogeneity and effective dose. When we compared the plan techniques for PTV-CA from the 14 Gy/1fraction dose distributions obtained, although there was no difference between D95 and D98 S-Arc and D-Arc techniques in dose coverage, it was determined that there was a 1.5% decrease in dose coverage and no significant difference in homogeneity and effective dose in dMLC technique as seen in Table 2. In the treatment plan located next to the PTV-BM brainstem critical organ, the brainstem tolerance dose was limited to a maximum of 15 Gy and 18 Gy/1fraction dose distribution to the PTV-BM target volume was calculated. Therefore, when we compare the plan techniques by accepting the losses for the D95 and D98 dose coverage shown in Table 3, a D95 dose value of approximately 16 Gy was obtained in the S-Arc and D-Arc techniques, while 17 Gy dose was obtained in the dMLC technique. Dmean and D50 were found to provide effective dose values of 18 Gy. In the S-Arc, D-Arc and dMLC treatment plans, Brain Steam maximum dose values were 1269.5, 1291.1 and 1362.5 cGy, respectively. S-Arc and D-Arc plans were compared in Table 4, it was found that MU numbers increased by 5.0% in PTV-VS, 9.4% in PTV-CA and 22.2% in PTV-BM in D-Arc plans. D-Arc plans are generally preferred to provide better PTV dose distributions between S-Arc and D-Arc Plans. For this reason, when dMLC plans are compared with D-Arc plans, differences were found between MU numbers in PTV-VS -0.7%, PTV-CA 9.4% and PTV-BM 8.4%.

Discussion

In this study, it was found that in PTV-VS plans; there was no difference between S-Arc and D-Arc in terms of D95 PTV dose coverage, in the PTV-CA plans; there was no difference between single arc and double arc in terms of D95 PTV dose coverage, but there was a loss of 0.004 cm3 and 0.42% in terms of D95 PTV dose coverage in dMLC plan. In PTV-BM plans; in terms of D95 PTV dose (1710 cGy) coverage between S-Arc and D-Arc, S-Arc 0.279 cm3 and 9.83%, D-Arc 0.27 cm3 and 9.53%, and in dMLC plan D95 PTV dose (1710 cGy) coverage 0.154 cm3 and 5.42%, respectively. According to this result, it was concluded that in PTV-VS and PTV-CA plans, both S-Arc and D-Arc techniques provided better PTV dose coverage than the dMLC technique because the PTV volumes were small. The effectiveness of the dMLC technique increases as the treatment volume (cc) increases. For PTV-VS volume (0.464 cc), no significant difference was observed between the MU numbers when dMLC plans were compared with D-Arc plans, so it can be concluded that there is no difference between these two treatment techniques for very small volumes. For PTV-CA (0.949 cc) and PTV-BM (2.859 cc), MU % differences increase as the volume increases. Therefore, when dMLC plans are compared with D-Arc plans, patient treatment times also increase in dMLC plans and D-Arc plans should be preferred as the PTV volume increases. On the other hand, stereotactic radiotherapy is a time-consuming treatment strategy. The shortening of the treatment time may decrease the undesirable movements, increase the patient's comfort, relieve patient's distress, and thus reduce treatment-related uncertainties in this group of patients.

Conclusion

In brain SRS, it has been shown that there is no significant difference between single arc, double arc VMAT and dMLC techniques in MU and dose rolls in treatments with small PTV volumes such as VS and CA, whereas in cases with larger treatment volumes such as BM, dMLC dose rolls are better despite the increase in the number of MUs and patient treatment time. In clinics, preferences should be made between these treatment planning techniques considering the number of patients and patient density.

Conflicts of Interest

There are no conflicts of interest and no acknowledgement.

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