VOLUME - 15, ISSUE - 06, JUNE - 2026 • PRINT ISSN No. 2277 - 8160 • DOI : 10.36106/gjra

Original Research Paper | Oncology & Radiotherapy

EVALUATION OF HIPPOCAMPAL AND SCALP SPARING IN WHOLE BRAIN RADIOTHERAPY USING VOLUMETRIC MODULATED ARC THERAPY TECHNIQUE WITH SINGLE AND DOUBLE ARC TECHNIQUE

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ABSTRACT This study compared dosimetric outcomes of single-arc and dual-arc VMAT for hippocampal-sparing whole-brain radiotherapy in 12 patients with brain metastases. Both techniques achieved clinical treatment requirements and adequate target coverage. However, dual-arc VMAT demonstrated superior conformity and homogeneity in hippocampal avoidance compared with single-arc VMAT. It also significantly reduced radiation dose to organs at risk (OARs) while maintaining treatment effectiveness. These findings indicate that dual-arc VMAT provides better hippocampal protection and overall normal tissue sparing, making it a more favorable approach for whole-brain radiotherapy in patients with brain metastases.

KEYWORDS : Hippocampal, Scalp Sparing, Single - Double Arc, VMAT.

INTRODUCTION

Whole-brain radiotherapy (WBRT) is a commonly used treatment for patients with brain metastases. However, because the brain contains several critical organs at risk (OARs), WBRT presents significant planning challenges [1], [2]. The most common prescription for WBRT is 30 Gy delivered in 10 fractions. During treatment planning, structures such as the optic chiasm, optic nerves, brainstem, hippocampus, lens, and scalp must be carefully spared. Although the maximum dose tolerance of the optic chiasm, optic nerves, and brainstem exceeds 30 Gy, hippocampal sparing is particularly important because the Radiation Therapy Oncology Group (RTOG) recommends a maximum hippocampal dose of less than 17 Gy [2-4]. Scalp sparing is also desirable to reduce radiation-induced alopecia, but achieving this is challenging due to the spherical shape of the head [6].

The hippocampus is a small, curved structure located in the medial temporal lobe and is a key component of the limbic system. It plays a crucial role in memory formation, learning, and emotional processing. Radiation-induced damage to the hippocampus has been associated with neurocognitive decline, and clinical studies suggest that many of the cognitive side effects observed after WBRT are related to hippocampal irradiation [2,5], [6,7]. Therefore, effective hippocampal sparing has become an important objective in modern WBRT planning.

Volumetric modulated arc therapy (VMAT) is an advanced radiotherapy technique that delivers radiation continuously while the gantry rotates around the patient. Beam intensity is dynamically modulated through precise movement of the multileaf collimator, enabling the radiation beam to conform closely to the planning target volume (PTV). This results in improved dose conformity and reduced dose to surrounding critical structures [9-10], [13-15]. Previous studies have demonstrated that VMAT provides superior target coverage and OAR sparing compared with 3DCRT and IMRT, making it a preferred technique for hippocampal-sparing WBRT [8-12], [16].

II. MATERIALS AND METHODS

Twelve previously treated whole-brain radiotherapy (WBRT) cases were retrospectively selected for this study. All patients had undergone CT simulation and MRI imaging. A 3 mm CT scan was acquired in the supine position, while MRI was performed for accurate delineation of brain structures. Axial and coronal fluid-attenuated inversion recovery (FLAIR), axial T2-weighted, and gadolinium-enhanced MRI sequences with 1.5 mm slice thickness were obtained to provide detailed brain anatomy. Delineation was performed by a radiation oncologist according to ICRU 83 guidelines. Critical organs at risk (OARs), including the brainstem, optic chiasm, optic nerves, hippocampus, scalp, and lenses, were contoured. A 4 mm margin was added around the hippocampus to create the hippocampal avoidance region following RTOG 0933 guidelines, while no additional margins were applied to account for uncertainties. Treatment planning was carried out using Monaco TPS version 5.11. A prescription dose of 30 Gy in 10 fractions was delivered to the planning target volume (PTV), ensuring that 95% of the prescribed dose covered at least 95% of the PTV, with hotspots limited to 107% of the prescription dose.

All plans used 6 MV photon beams and the Monte Carlo dose calculation algorithm. Each case was planned using both single-arc and dual-arc VMAT techniques, with the dual-arc plan generated first and subsequently converted to a single-arc plan for dosimetric comparison. Plan evaluation was based on dose–volume histograms (DVHs), target coverage, conformity index (CI), and homogeneity index (HI). Dosimetric parameters were assessed against RTOG 0933 criteria, with preference given to plans achieving optimal target coverage and maximal OAR sparing.

$$CI = Vri/TV$$

where Vri = Volume covered by the 95% isodose TV = Target Volume. The CI value range 1 corresponds to the supreme dose coverage or maximum conformity. The conformity index > 1 indicates that treated volume exceeds the target volume and covers part of the unwanted tissue. If the conformity index is between 1 and 2, the treatment is in according to the protocol,if it is > 2.5 and < 0.9 it is examined as a serious deviation from protocol [17].

HI denotes whether the dose received by the target volume is homogeneous or not. The formula chosen for this study is,

$$HI = (D5\text{-}D95)/D50$$

Where HI = Homogeneity index D5= Dose receiving on 5% of PTV, D95 = Dose receiving on 95% of PTV D50= Dose receiving on 50% of PTV. The lower the index value, i.e. closer to 0, better the dose homogeneity. The index value however increases with lesser homogeneous plans [18].A paired t-test was used to compare the two planning techniques. The analysis assumed the null hypothesis that no difference existed between the techniques. A significance level of 5% (= 0.05) was selected. The p-value was calculated from the collected data. If p > 0.05, no statistically significant difference was observed, and the null hypothesis was accepted. If p < 0.05, a statistically significant difference was observed, and the alternative hypothesis was accepted. Statistical analysis was performed using SPSS version 16.0. Mean values and standard deviations for the evaluated parameters were calculated and tabulated for both planning techniques.

III. RESULTS AND DISCUSSION

This study compared single-arc and dual-arc VMAT techniques for hippocampal- and scalp-sparing whole-brain radiotherapy. PTV evaluation included conformity index (CI), homogeneity index (HI), integral dose, V95, V110, Dmean, Dmax, and monitor units per fraction (MU/#). Dual-arc VMAT demonstrated significantly better target coverage, with higher V95 (92.29% vs. 89.89%, p<0.001) and improved homogeneity (HI: 0.168 vs. 0.204, p<0.05). Although CI differed significantly (1.175 vs. 1.144, p=0.033), both techniques showed acceptable conformity. Dual-arc plans exhibited higher V110 (3.41% vs. 2.01%, p=0.003), indicating a greater hotspot volume. No significant differences were observed in integral dose, Dmean, or Dmax of the PTV. Additionally, dual-arc VMAT required significantly fewer monitor units per fraction (1361 vs. 1464, p=0.012), suggesting improved delivery efficiency.

For organs at risk, dual-arc VMAT achieved superior hippocampal sparing, with significantly lower hippocampal Dmax (1680.58 vs. 1733.33 cGy, p<0.001) and D100 (1106 vs. 1168.67 cGy, p=0.001). However, scalp Dmean was slightly higher with dual-arc VMAT (990.51 vs. 939.18 cGy, p=0.013), indicating better scalp sparing with the single-arc technique.

Overall, dual-arc VMAT provided improved target coverage, dose homogeneity, treatment efficiency, and hippocampal protection, whereas single-arc VMAT offered superior scalp sparing. Therefore, dual-arc VMAT appears to be the preferred technique when hippocampal sparing is the primary clinical objective.

Table 1. Comparison Between Single Arc VMAT Technique and Dual Arc VMAT Technique in Terms of PTV.

PARA-METERS	SINGLE ARC VMAT	DUAL ARC VMAT	P-VALUE
CI	1.144±0.049	1.175±0.057	0.033
HI	0.204±0.031	0.168±0.040	0.001
ID	40827.542±6893.344	40998.778±6895.685	0.099
V95	89.894±1.540	92.290±1.384	0.000
V110	2.005±0.524	3.414±1.529	0.003
Dmean	3052.566±21.690	3101.589±188.207	0.380
Dmax	3683.125±33.210	3663.233±69.746	0.395
MU/#	1463.786±188.8	1361.316±166.8	0.012

Table 2. Comparison Between Single Arc VMAT Technique and Dual Arc VMAT Technique in Terms of OAR

CRITICAL ORGAN	PARA-METER	SINGLE ARC VMAT	DUAL ARC VMAT	P-VALUE
HIPPO-CAMPUS	Dmax	1733.328 ± 41. 211	1680.580 ± 31.223	0.000
	D100	1168.673 ± 78. 812	1106 ± 211	0.001
SCALP	Dmean	939.178 ± 230. 510	990.508 ± 250.466	0.013

The study compared single-arc VMAT and dual-arc VMAT techniques using various dosimetric evaluation parameters. Some parameters favored single-arc VMAT, while others favored dual-arc VMAT. The conformity index (CI) and V110 were more favorable for single-arc VMAT. Since a CI value closer to 1 indicates a more conformal plan, single-arc VMAT demonstrated slightly better conformity, although dual-arc VMAT values were also close to 1. Lower V110 values indicate reduced unwanted high-dose regions, and single-arc VMAT achieved lower V110 values.

Dual-arc VMAT showed advantages in homogeneity index (HI), V95, Dmax, and Dmean. A lower HI indicates better homogeneity, and dual-arc VMAT produced values closer to zero. V95 values closer to 100% indicate superior target coverage, which was achieved by dual-arc VMAT. However, differences in Dmax, Dmean, and integral dose between the two techniques were not statistically significant.

Dual-arc VMAT also required fewer monitor units (MU), indicating more efficient dose delivery. Hippocampal sparing was superior with dual-arc VMAT, meeting the RTOG 0933 criterion of Dmax <17 Gy, whereas single-arc VMAT exceeded this limit. Neither technique achieved the recommended hippocampal D100 <10 Gy. Both techniques successfully spared the scalp (Dmean <18 Gy), with single-arc VMAT delivering a slightly lower scalp dose.

IV. CONCLUSION

In this study of 12 WBRT cases, dual-arc VMAT demonstrated superior PTV coverage and dose homogeneity while maintaining OAR doses within prescribed limits. Improved conformity and homogeneity may enhance tumor control, and better OAR sparing may reduce complications, indicating that dual-arc VMAT provides better overall plan quality than the compared technique.

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