Iranian Journal of Medical Physics

ijmp.mums.ac.ir

Comparison of Volumetric Modulated Arc Therapy and Three-Dimensional Conformal Radiotherapy in Postoperative High-Grade Glioma: A Dosimetric Comparison

Harikesh Bahadur Singh[1], Ajeet Kumar Gandhi[1], Shantanu Sapru[1], Rohini Khurana[1], Rahat Hadi[1], Sambit Swarup Nanda[1], Satyajeet Rath[1], Avinav Bharati[1], Anoop Kumar Srivastava[1], Surendra Prasad Mishra[1], Kamal Sahni[1], Nuzhat Husain[1], Madhup Rastogi[1*]

1. Department of Radiation Oncology, Dr. Ram Manohar Lohia, Institute of Medical Sciences, Vibhuti khand, Gomti Nagar, Lucknow, India

ARTICLE INFO

Article type:
Original Article

Article history:
Received: Nov 14, 2018
Accepted: Mar 03, 2019

Keywords:
Glioma
Computer-Assisted Radiotherapy Planning
Volumetric Modulated Arc Therapy
Three-Dimensional Conformal Radiotherapy

ABSTRACT

Introduction: We aimed to dosimetrically compare three-dimensional conformal radiotherapy (3D-CRT) and volumetric modulated arc therapy (VMAT) in terms of planning target volume (PTV) coverage, organ at risk (OAR) sparing, and conformity index (CI).

Material and Methods: Planning data of 26 high grade glioma (HGG) patients were used. Prescribed dose for 3D-CRT was 46Gy in 23 fractions to low-risk PTV (LR-PTV) and 14 Gy in 7 fractions to high-risk PTV (HR-PTV). VMAT plans were conducted using 46 Gy in 30 fractions to LR-PTV and 60 Gy in 30 fractions to HR-PTV.

Results: Tumor locations were frontal, parietal, temporal, and multi-lobed in 27%, 15%, 23%, and 35% of cases, respectively. Histology was glioblastoma multiform in 89% of patients. Mean values of PTV D95 (dose received by 95% volume) in 3D-CRT and VMAT were 96.6% and 98.8% for the LR-PTV and 97.3% and 99% for HR-PTV (P<0.001), respectively. Mean values of CI in 3D-CRT were 0.96 and 0.97 for LR-PTV and HR-PTV and 0.98 and 0.99 for LR-PTV and HR-PTV of VMAT (both P<0.001), respectively. Mean Dmax of right optic nerve (maximum point dose received by the organ) for 3D-CRT and VMAT were 31.59 and 25.57Gy (P=0.02). Mean Dmax for left optic nerve and optic chiasm were 28.81 and 22.14 Gy (P=0.019) and 42.24 and 37.12 Gy (P=0.055) respectively for 3D-CRT versus VMAT. Doses to other OARs were not statistically different between 3D-CRT and VMAT.

Conclusion: VMAT achieved better coverage of the PTV and delivered fewer doses to bilateral optic nerve and chiasm.

► *Please cite this article as:*
Singh H.B., Gandhi A.K., Sapru Sh, Khurana R, Hadi R, Nanda S.S., Rath S, Bharati A, Srivastava A.K., Mishra S.P., Sahni K, Husain N, Rastogi M. Comparison of Volumetric Modulated Arc Therapy and Three-Dimensional Conformal Radiotherapy in Postoperative High-Grade Glioma: A Dosimetric Comparison. Iran J Med Phys 2019; 16: 385-391. 10.22038/ijmp.2019.35300.1452.

Introduction

Primary parenchymal brain tumors account for 85-90% of all primary central nervous system (CNS) tumors [1]. High-grade glioma (HGG), including anaplastic glioma and glioblastoma multiforme (GBM), includes approximately half of the primary brain tumors [2]. The management of HGG has remained a challenge despite the improvements in surgical techniques, radiotherapeutic modalities, and chemotherapy treatment.

Maximal safe resection (MSR) followed by radiotherapy (RT) with concurrent and adjuvant temozolomide remains the gold standard for the management of GBM [3, 4]. Surgical and radiotherapy approaches toward anaplastic glioma and GBM are similar. Despite the advancements in various therapeutic approaches, prognosis remains dismal with median survival of 11-18 months for GBM [5]. Estimated median overall survival (OS) varies widely and ranges 15-40 months for anaplastic glioma, with some anaplastic oligodendroglioma (AO) patients (1p/19q co-deleted tumors) demonstrating a median survival of exceeding 56 months [6, 7].

The commonly practiced radiotherapeutic technique is three-dimensional conformal radiotherapy (3D-CRT); however, it is limited to deliver an enhanced dose to the target volume with inefficient sparing of organs at risk (OARs). Advanced RT techniques, such as intensity modulated RT (IMRT) and volumetric modulated arc therapy (VMAT), have the potential to reduce the doses to OAR while delivering the same or better doses to target volumes. IMRT represents significant advantage over 3D-CRT [8] in terms of tumor dose coverage, better conformity, and better sparing of OAR observed in glioma [9,10]. Relatively shorter treatment time,

*Corresponding Author: Tel: +91-8176007010; E-mail: drmadhup1@gmail.com

resulting in lesser intra-fraction motion susceptibility with the same degree of conformity as IMRT makes VMAT a more convenient method of RT delivery in a resource constraint setup [11-13]. Although there has been a body of literature on the comparison of IMRT with VMAT in HGG patients, there is no research addressing direct head-to-head comparisons of 3D-CRT with VMAT in the postoperative status of HGG patients.

Therefore, the present study aimed to provide a precise comparison of 3D-CRT with VMAT in the postoperative status of HGG patients. This comparison was conducted in terms of planning target volume (PTV) coverage, OAR sparing, biologically effective dose (BED) of respective volumes, conformity index (CI), and homogeneity index (HI).

Materials and Methods

Participants

This is a prospective observational study of 26 patients enrolled between July 2015 and August 2016 with due approval from the institutional ethics committee (Code No. of IEC: 19/15). The inclusion criteria in the current study were a) male and female patients in the postoperative status, b) grade III and IV of AO, anaplastic astrocytoma (AA), and GBM (histopathologically proven based on World Health Organization), c) age range of 18-70 years, d) normal renal function test, e) liver function test, and f) adequate bone marrow reserve. On the other hand, patients with the multi-centric disease, prior history of any malignancy, and exposure to any form of chemotherapy or radiotherapy were excluded from the study. Informed written consent form was obtained from all patients prior to initiation of the study. The investigated patients in the current study were exposed to MSR. Patient and tumor characteristics are summarized in tables 1 and 2, respectively.

Table 1. Patient characteristics at the baseline

Characteristic	Statistical analysis
Age (years)	
18-29	2
30-49	12
≥50	12
Median age	46.5
Gender	
Male	20
Female	6
KPS	
70	4 (15.38%)
80	8 (30.76%)
90	14 (53.84%)
Median	90

KPS: Karnofsky performance score

Image Acquisition

Post-operative magnetic resonance imaging (MRI) was obtained in the treatment position to enable MRI-CT fusion during RT planning. Subsequently, contrast-enhanced computed tomography (CECT) simulation was performed on CT simulator (SOMATOM, SIEMENS, Germany) in a supine position using a thermoplastic cast for immobilization. CT images were acquired at a slice thickness of 3 mm and the obtained data were transferred to the treatment planning system (MONACO Version 5.0, ELEKTA, Crawley, UK) using DICOM protocol 3.0. T1 contrast and T2 FLAIR sequences of MRI obtained in DICOM format were fused using the auto fusion software. Auto-fusion facility was utilized for the image fusion and avoidance of any distortion using image optimization algorithm in data transfer and fusion protocol. This facility is based on the mutual information of statistical similarities between the areas of interest. Repetitive iterations were performed to obtain satisfactory fusion (as evident on the serial axial, coronal and sagittal images in fusion window).

Table 2. Tumor characteristics

Side of involvement	Statistical analysis	
Left	12 (46.15%)	
Right	14 (53.84%)	
Location	Left	Right
Frontal	2 (7.69%)	5 (19.23%)
Fronto-parietal	2 (7.69%)	-
Fronto-temporal	1 (3.84%)	-
Parietal	2 (7.69%)	2 (7.69%)
Temporo-parietal	2 (7.69%)	4 (15.38%)
Temporal	3 (11.5%)	3 (11.53%)
Histopathology		
GBM†	23 (88.46%)	
AO†	2 (7.69%)	
AA†	1 (3.84%)	

GBM: Glioblastoma multiforme, AO: Anaplastic oligodendroglioma, AA: Anaplastic astrocytoma

Target Volume delineation

The demarcation of the volumes were performed based on standard guidelines [14,15]. Gross tumor volume (GTV) was defined as contrast enhancing tumor (residual tumor). Clinical target volume (CTV) corresponded to GTV plus post-resection cavity with a margin to include potential microscopic extensions. Two different types of CTVs, namely high-risk CTV (HR-CTV) and low-risk CTV (LR-CTV) were taken into consideration. The HR-CTV was contoured based on 1.5-2.0 cm margin to T1 enhancement (GTV) plus resection cavity. The LR-CTV included the volume of T2 FLAIR MRI enhancement with a 1.5-2.0 cm margin. The CTVs were limited by anatomical boundaries. HR-CTV and LR-CTV were expanded with 5 mm isotropic margin to obtain HR-PTV and LR-PTV respectively. Similar PTV margins were applied for both 3D-CRT and VMAT [16]. Delineated OARs were brainstem, bilateral optic nerves, optic chiasm, bilateral eyes, and lenses. Target and OARs volume for the investigated patients were the same in both 3D-CRT and VMAT groups, thereby minimizing inter-observer variability in the delineation of volumes.

Radiotherapy Treatment Planning

In order to conduct radiotherapy treatments, two different plans were generated in the current study. The 3D-CRT plans were generated using a treatment planning system (XIO Version 5.0 ELEKTA, Crawley, UK) through forward planning to the total dose of 60 Gy in two phases. In phase 1, 46 Gy was planned in 23 fractions (5 fractions per week) to LR-PTV followed by 14 Gy in 7 fractions (5 fractions per week) Multiple fields either coplanar or non-coplanar with motorized wedges were used, and field shaping was performed through multi-leaf collimator (MLCs) [17]. The VMAT planning was performed using MONACO (Version 5.0, ELEKTA, Crawley, UK) on the same patients using the similar target volume and OAR as utilized for 3D-CRT plans. The VMAT plans were sequentially optimized with the interplay of multi-leaf collimators and weight of treatment planning beams [18]. In the VMAT plans, 60 Gy in 30 fractions were planned to HR-PTV and 46 Gy in 30 fractions to the LR-PTV using a simultaneous integrated boost technique.

For both 3D-CRT and VMAT, plans were created for achieving $\geq$95% of PTV being covered by $\geq$95% isodose line while considering the dose limits of OARs. Moreover, hot spots (>110% of the prescription doses) were limited to < 20% of PTV and restricted to <2% of the outside PTV. Regarding OARs, the tolerance dose was considered as maximum dose (Dmax; ≤54 Gy) for the brainstem [19] and point dose ≤ 60 Gy if PTV encompassed brainstem, ≤ 54 Gy (Dmax) to the optic nerve, ≤ 54 Gy (Dmax) to optic chiasm. Additional criteria for the patients were Dmax of ≤ 45 Gy for the spinal cord, Dmean of the eye ≤ 50 Gy, and Dmax to the lens ≤ 10 Gy [20, 21]. In order to calculate the BED, a linear quadratic model with α/β of 10 was employed in this study. The BED and equivalent dose at 2 Gy (EQD2) were separately calculated for respective volumes to meet the target goal and have a meaningful comparison.

All patients were treated using the 3D-CRT plans. VMAT plans were used only for the comparison of dosimetric parameters with 3D-CRT plans. Treatment was executed on high energy LINAC (ELEKTA infinity, Crawley, UK) with multi-leaf collimator (MLC) having a leaf width of 1 cm at the iso-center. Treatment verification was performed using cone beam CT (ELEKTA, Crawley, UK), daily for the first three fractions, and thereafter once a week for the remaining fractions.

Dosimetric Parameters and Statistical Analysis

Dosimetric comparison of 3D-CRT plans were made with VMAT plans in terms of PTV coverage, doses to OAR, CI, HI, BED, and EQD2. The dose volume histogram included Dmax and Dmean for PTV and OAR. Planning was evaluated by the assessment of slice-by-slice coverage as well as the use of dose volume histograms (DVH). The formulation used for conformity index was V_{RI}/TV, *where* V_{RI} is the volume covered by 95% of the isodose lines (reference isodose) and TV is the target volume. Similarly, the formulation used for homogeneity Index was I_{max} / RI, *where* I_{max} is the maximum isodose in the target and RI is reference isodose [10, 22, 23]. Statistical analysis was performed using SPSS software (version 20.0; SPSS, Inc., Chicago, IL, USA).

Results

Median volume of HR-PTV60 and LR-PTV 46 were 278.65cc (range: 157.8-560.80cc) and 458.19cc (range 262.54 to 806.86cc), respectively. PTV coverage at 95% of prescribed dose for LR-PTV was 96.66% and 98.88% (95% CI: -3.23 to -1.20, P≤0.001) and for HR-PTV was 97.38% and 99.01% (95% CI: 2.39 to -0.87, P≤0.001) for 3-D CRT versus VMAT plans, respectively. Comparative analysis of target volume coverage in 3D-CRT and VMAT plans are presented in Table 3 and the representative dose color wash of comparative plans is demonstrated in Figure 1. VMAT plans had a better mean CI compared to 3D-CRT in terms of both HR-PTV and LR-PTV. However, as can be seen in Table 3, both plans had a similar value regarding the mean HI with an insignificant advantage in favor of 3D-CRT. Comparative dosimetric results of OARs are tabulated in Table 4. Mean Dmax of right optic nerve (maximum point dose received by the organ) for 3D-CRT and VMAT were 31.59 and 25.57Gy (P=0.02). Mean Dmax for left optic nerve and optic chiasm were 28.81 and 22.14 Gy (P=0.019) and 42.24 and 37.12 Gy (P=0.055) respectively for 3D-CRT versus VMAT. Doses to other OARs were not statistically different between 3D-CRT and VMAT.

There was no significant difference in monitor units (MU) delivered between 3D-CRT and VMAT (561.42 vs. 560.90, P=0.99). However, the obtained results indicated the mean treatment time of 3.86 min and 3.22 min, as well as the median treatment time of 3.70 min (range: 2.4-5.3 min) and 3.08 (range: 2.0-4.41 min) for 3D-CRT and VMAT, respectively. As can be seen, VMAT was 1.2 times faster than 3D-CRT.

Table 3 shows the mean BED and EQD2 for both HR-PTV and LR-PTV in 3D-CRT and VMAT plans. Accordingly, VMAT plans delivered a significantly higher mean BED dose to HR-PTV, compared to 3D-CRT (P=0.006). Regarding LR-PTV, although the mean BED was higher in VMAT plans than 3D-CRT plans, it failed to reach the level of statistical significance (P=0.70).

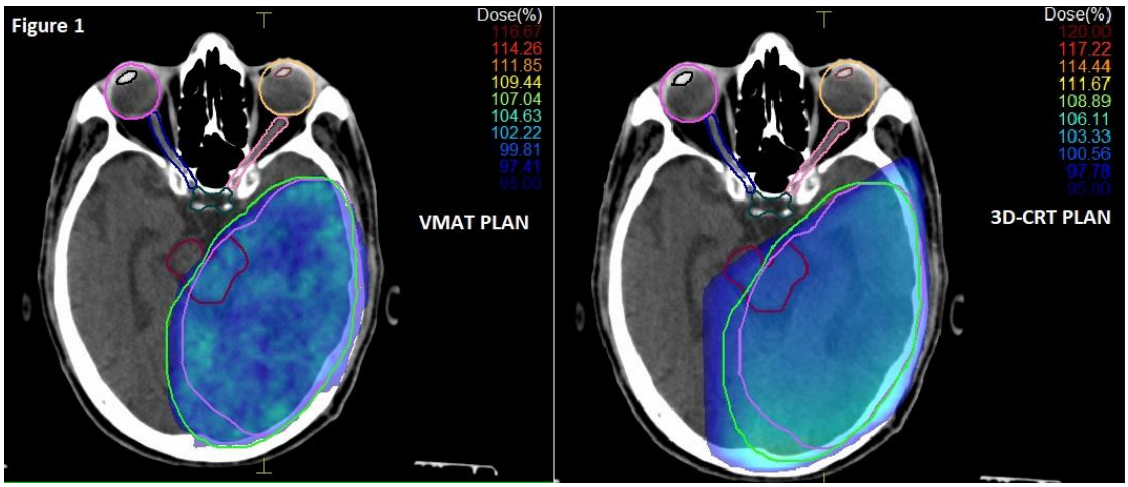

Figure 1. Comparative dose color wash at 95% isodose for volumetric modulated arc therapy and three-dimensional conformal radiotherapy plans. Contoured volume in green colour indicated low risk PTV and in pink colour indicates high risk PTV.

Table 3. Comparison of the dosimetric parameters of target volume

Target	3DCRT	VMAT	Relative change	95% Confidence interval	P Value
PTV Coverage at D95_LRPTV	96.66	98.88	2.24	-3.23 to -1.20	<0.001
LRPTV(Max dose)	62.21	64.26	3.19	-4.50 to 0.403	0.098
LRPTV(Mean dose)	57.65	57.97	0.5	-2.21 to 1.57	0.730
LRPTV(Mean BED)	68.72	69.20	0.7	-3.01 to 2.05	0.700
LRPTV(Mean EQD2)	57.25	57.72	0.8	-2.58 to 1.65	0.656
PTV Coverage at D95_HRPTV	97.38	99.01	1.64	-2.39 to -0.87	<0.001
HRPTV(Max dose)	64.39	64.78	0.6	-1.07 to 0.289	0.246
HRPTV(Mean dose)	60.27	61.07	1.3	-1.34 to -0.26	0.005
HRPTV (Mean BED)	72.38	73.54	1.5	-1.94 to -0.366	0.006
HRPTV(Mean EQD2)	60.36	61.32	1.5	-1.62 to -0.30	0.006
CI-LRPTV	0.96	0.98	2.04	-0.032 to -0.011	0.000
CI-HRPTV	0.97	0.99	2.02	-0.025 to -0.009	0.000
HI-LRPTV	1.40	1.46	4.1	0.120 to -0.002	0.059
HI-HRPTV	1.12	1.13	0.8	-0.018 to 0.005	0.263

3D-CRT: Three-dimensional conformal radiotherapy, VMAT: Volumetric modulated arc therapy, CI-LRPTV: Conformity index for low-risk planning target volume, D95: Dose received at 95% of isodose, CI-HRPTV: Conformity index high-risk planning target volume,
HI-HRPTV: Homogeneity index high-risk planning target volume, HI-LRPTV: Homogeneity index low-risk planning target volume, MU: Monitor unit, BED: Biological equivalent dose, EQD2: Equivalent dose at 2 Gy

Table 4. Comparison of the dosimetric parameters of organ at risk

		3DCRT	VMAT	95%Confidence interval	Relative reduction	P value
Brainstem	Dmax	50.60	49.08	-1.50-4.53	3	0.311
	Dmean	27.74	23.75	(1.09-6.88	14.3	0.009
Right optic nerve	Dmax	31.59	25.57	0.86-11.17	18.4	0.024
	Dmean	17.42	16.11	-3.12-5.74	7.52	0.548
Left optic nerve	Dmax	28.81	22.14	1.17-12.16	23.15	0.019
	Dmean	15.51	13.81	-3.08-6.47	10.9	0.472
Optic chiasm	Dmax	42.24	37.12	-0.11-10.37	12.12	0.05
	Dmean	33.00	26.09	0.93-12.89	20.9	0.025
Right lens	Dmax	5.71	9.28	-7.94-0.80	-38.4	0.105
	Dmean	4.37	7.24	-6.59-0.85	-39.6	0.125
Left lens	Dmax	5.08	9.33	-8.32 to -0.19	45.5	0.041
	Dmean	3.34	6.50	-6.07 to -0.24	48.61	0.035
Right eye	Dmax	20.47	22.89	-7.57 to -0.19	-10.5	0.344
	Dmean	6.80	9.61	-6.78 to -1.14	-29.2	0.156
Left eye	Dmax	5.08	9.33	-4.26 to -0.19	-45.51	0.041
	Dmean	3.34	6.50	-6.07 to -0.242	-48.6	0.035

3D-CRT: 3dimensional conformal radiotherapy, VMAT: Volumetric modulated arc therapy
Dmax: Maximum dose received by organ, Dmean: Mean dose received by organ

Discussion

It is essential to mention that 3D-CRT delivers a conformal dose distribution to the tumor using uniform beam intensities within each beam portal. RT in HGG is typically delivered with 3D-CRT. Recent advancements in the radiotherapy techniques have led to the better conformity of doses to the target while sparing the organs at risk to as much as possible [24-27].

In VMAT technique, RT is delivered in a continuous arc as the beam portals are modulated via the multi-leaf collimator to conform to the PTV. Moreover, the intensity is modulated incorporating a multifactorial approach, which allows modulations using variable dose rate and gantry speed [28]. VMAT technique has the connotation of dose painting on the delineated targets and thus has enhanced the probability of dose escalation in PTV and dose limitation in OARs.

Studies analyzing 3D-CRT and IMRT in different tumor sites have compared dosimetric parameters between these two modalities. However, there are a limited number of comparative studies evaluating 3D-CRT versus VMAT in the postoperative status of HGG patients. The current study compared VMAT with 3D conformal technique among HGG patients. To the best knowledge of the researchers, only two published studies have compared VMAT and 3D-CRT/IMRT so far, which are presented in Table 5.

Wagner et al. [29] compared three modalities, namely single arc VMAT, multifield (5-9) IMRT, and 3D-CRT in 14 HGG patients. The obtained results revealed that VMAT and IMRT had better conformity than 3D-CRT plans. The obtained results revealed that OAR is related to the PTV situation, meaning that VMAT and IMRT had an edge over 3D-CRT in PTVs situated near the OARs. However, the same was not proved for PTV that were away from OARs. The coverage of PTV was better in IMRT, as compared to that of VMAT (94.7% vs. 90.5%). Furthermore, the coverage rates of VMAT and 3D-CRT were reported as 90.5% and 81.2%, respectively (95% CI:0.89-0.63). In our study, an attempt was made to cover 95% of PTV by 95% isodose line (IDL) in both plans. On analysis, 95% PTV coverage was found to be significantly higher in VMAT plan, compared to 3D-CRT plan for both HR-PTV (99.01% vs. 97.38%, $P \leq 0.001$) and LR-PTV (98.88% vs. 96.66%, $P \leq 0.001$) groups. In VMAT plans, 95% IDL for HR-PTV covered > 98% volume in 100% cases. In 3D-CRT plans, for HR-PTV 95% IDL covered > 98% in only 42% of cases, thus showing the superiority of VMAT over 3D-CRT in terms of HR-PTV coverage. Regarding VMAT, for LR-PTV 95% IDL covered > 98% and 95-98% volume of PTV in 88.46% and 7.65% cases, respectively. On the other hand, the compromised plan of 95% IDL covering 93% LRPTV was accepted to attain optic chiasm constraint for one patient. It is worth mentioning that the current study did not address the comparative dosimetric outcomes based on the proximity of the PTV to OARs in our study.

Table 5. Main characteristics of the treatment planning studies concerning volumetric modulated arc therapy and three-dimensional conformal radiotherapy in high-grade glioma

Authors	Prescription and Fractionation	Site of lesions	Volumes	OAR	MU	Treatment time
Wagner et al [29]	3D-CRT: 59.4 Gy to PTV (1.8 Gy/fraction) IMRT: 60 Gy to PTV (2 Gy/fraction) VMAT: same as IMRT	N/R	PTV: mean 432.9 cc, range (310.9–815.2) cc	VMAT slightly better than IMRT and 3D-CRT for OAR sparing (Chiasm, brainstem). VMAT – highest mean dose to normal brain and V5Gy of healthy tissue	VMAT, 321.1; IMRT, 587.8; 3D-CRT, 224	VMAT" 5.6 times faster than IMRT; 1.26 faster than 3D-CRT
Shaffer et al [30]	S-IMRT: 60 Gy to PTV (2 Gy/fraction) VMAT: same as S-IMRT	N/R	PTV: mean 343 cc, Similar PTV coverage, conformity and homogeneity	VMAT better than IMRT at sparing Lateralized OARs (retina, lens, optic nerves). No significant differences in sparing of centralized OARs (brainstem, Chiasm). VMAT – higher mean dose to normal brain (by 12%)	VMAT, 363; IMRT, 789	VMAT: 1.8 min, IMRT: 5.1 min
Present study	3D-CRT: LRPTV-46Gy(23fraction) followed by 14Gy (7fraction) boost to HRPTV VMAT: LRPTV-46Gy (30fraction) with SIB 60 Gy (30fraction) to HRPTV	Recorded	Median volume of HRPTV and LRPTV were 278.65cc and 458.19cc	VMAT achieved better PTV coverage and significantly spared optic apparatus better compared to 3D-CRT plans.	3DCRT-561.42; VMAT-560.90	3D-CRT:-3.86 min, VMAT: 3.22

3D-CRT: Three-dimensional conformal radiotherapy, VMAT: Volumetric modulated arc therapy, IMRT: Intensity modulated radiotherapy, PTV: Planning target volume, OAR: Organs at risk, S-IMRT: Static intensity modulated radiotherapy; HRPTV: High-risk planning target volume, LRPTV: Low-risk planning target volume, MU: Monitor unit

Shaffer et al. [30] compared VMAT to multifield fixed beam IMRT in 10 HGG patients. The investigated patients were also required to have their PTV overlapped by at least one OARs. The VMAT and IMRT were similar in the sparing of brainstem and optic chiasma; however, delivered lower doses to the retina, lens, and optic nerve. Target volume coverage and conformality were equivalent in both treatment arms. However, this study did not compare VMAT with 3D-CRT plans. Taking into account that only patients with PTV overlapping with at least one OARs, it would be of utmost importance to have the comparative analysis of 3D-CRT versus VMAT in this study.

Zach et al. [31] in a dosimetric study comparing 3D-CRT, sequential boost IMRT, simultaneous integrated boost (IB) IMRT, and tomotherapy plans in HGG showed that mean dose to the optic chiasm and the ipsilateral globe were the highest with 3D-CRT plans and the least with IB IMRT plans.

Dosimetric comparison of 3D-CRT and VMAT plans in the present study revealed that VMAT plans lead to the better coverage of the target volume with the better sparing of some OARs, such as optic apparatus. The sparing of OAR is limited by the complexity of the tumor location and overlap of the target volumes with OARs volume. However, a better conformal plan with better sparing of optic nerve and chiasm in comparative plans of 3D-CRT versus VMAT suggests the preferential use of the latter as compared to the former. The accurate delineation of target volumes on CT/MRI fused images has not been done by previous studies [29,30]. The sparing of optic chiasm in the current study was like the findings noted by Wagner et al [29]. However, brainstem sparing was not observed in the current study as opposed to the study by Wagner et al [29]. The differential sparing of OARs noted by Shaffer et al. [30] is the result of the complex interplay of the topographical relationship of PTV and OARs.

This study is not a direct comparison between two techniques in terms of clinical outcomes since all the patients were planned and treated using 3D-CRT, and subsequently planned for VMAT for dosimetric comparison. It is observed that VMAT allows a higher level of percentage dose delivery and better conformity than 3D-CRT. The VMAT facilitates the selection of arc rotation, provides better conformity to the target volume due to dose variations in the beam, reduces spillage to OARs without significantly enhancing the monitor units (MU's). VMAT has the potential to increase the therapeutic window of radiation therapy for the treatment of HGG. However, the advantage of 3D-CRT is that it uses less MU and spillage of low dose to other areas. 3D-CRT may be still valuable in the areas, where PTV is far off from OARs. The dosimetric evaluation of VMAT illustrates that the high degree of conformity is practicable in the regions, where OARs are more proximal without surpassing the dose constraints of OARs.

Although this study provides profound insights, conducting similar VMAT plan evaluations on a large sample size will provide more generalizable results using this new emerging modality in the radiotherapy of HGG.

Conclusion

VMAT compared to 3D-CRT achieved statistically significant sparing of the optic nerves and chiasm with better coverage of the PTV in the postoperative status of HGG patients planned for adjuvant radiotherapy. The selection of arcs in VMAT, where the right or left optic nerve, chiasm, and eyes/lens are more proximal to the tumor volume, might suffer from some limitations. A personalized approach towards the selection of treatment technique (3D-CRT, VMAT, IMRT) based on the location and volume of PTV with respect to the OARs may be the best way to optimize the management decisions.

References

1. Ostrom QT, Gittleman H, Fulop J, Liu M, Blanda R, Kromer C, et al. CBTRUS Statistical Report: Primary Brain and Central Nervous System Tumors Diagnosed in the United States in 2008-2012. Neuro Oncol. 2015;17:1-62.
2. Siker ML, Donahue BR, Vogelbaum MA. Primary Intracranial Neoplasms. In: Halperin EC, Parez CA, Brady LW, editors. Perez and Brady' s Principles and Practice of Radiation Oncology. 5th ed. Philadelphia: Lippincott Williams and Wilkins; 2008;718-50
3. Stupp R, Hegi ME, Mason WP, van den Bent MJ, Taphoorn MJ, Janzer RC, et al. Effects of radiotherapy with concomitant and adjuvant temozolomide versus radiotherapy alone on survival in glioblastoma in a randomised phase III study: 5-year analysis of the EORTC-NCIC trial. Lancet Oncol. 2009;10(5):459‑66.
4. Stupp R, Mason W, van den Bent MJ, Weller M, Fisher BM, Taphoorn MJB, et al. Radiotherapy plus Concomitant\nand Adjuvant Temozolomide for Glioblastoma. N Engl J Med. 2005; 352(10):987-96.
5. Tran B, Rosenthal MA. Survival comparison between glioblastoma multiforme and other incurable cancers. J Clin Neurosci. 2010 ;17(4):417-21.
6. Nuño M, Birch K, Mukherjee D, Sarmiento JM, Black KL, Patil CG. Survival and prognostic factors of anaplastic gliomas. Neurosurgery. 2013;73(3):458‑65.
7. Cairncross G, Wang M, Shaw E, Jenkins R, Brachman D, Buckner J, et al. Phase III trial of chemoradiotherapy for anaplastic oligodendroglioma: Long-term results of RTOG 9402. J Clin Oncol. 2013;31(3):337‑43.
8. Hermanto U, Frija EK, Lii MJ, Chang EL, Mahajan A, Woo SY. Intensity-modulated radiotherapy (IMRT) and conventional three-dimensional conformal radiotherapy for high-grade gliomas: Does IMRT increase the integral dose to normal brain?. Int J Radiat Oncol Biol Phys. 2007;67(4):1135‑44.
9. Chan MF, Schupak K, Burman C, Chui C-S, Ling CC. Comparison of intensity-modulated radiotherapy with three-dimensional conformal radiation therapy planning for glioblastoma multiforme. Med Dosim. 2003;28(4):261‑5.
10. Narayana A, Yamada J, Berry S, Shah P, Hunt M, Gutin PH, et al. Intensity-modulated radiotherapy in

high-grade gliomas: Clinical and dosimetric results. Int J Radiat Oncol Biol Phys. 2006;64(3):892-7.
11. Vanetti E, Clivio A, Nicolini G, Fogliata A, Ghosh-Laskar S, Agarwal JP, et al. Volumetric modulated arc radiotherapy for carcinomas of the oro-pharynx, hypo-pharynx and larynx: A treatment planning comparison with fixed field IMRT. Radiother Oncol. 2009;92(1):111-7.
12. Zheng BM, Dong XX, Wu H, Duan YJ, Han SK, Sun Y. Dosimetry comparison between volumetric modulated arc therapy with rapidarc and fixed field dynamic IMRT for local-regionally advanced Nasopharyngeal Carcinoma. Chinese J Cancer Res. 2011;23(4):259-64.
13. Doornaert P, Verbakel WF a R, Bieker M, Slotman BJ, Senan S. RapidArc planning and delivery in patients with locally advanced head-and-neck cancer undergoing chemoradiotherapy. Int J Radiat Oncol Biol Phys. 2011;79(2):429-35.
14. Stroom JC, Heijmen BJM. Geometrical uncertainties, radiotherapy planning margins, and the ICRU-62 report. Radiother Oncol. 2002;64(1):75-83.
15. International Commission on Radiation Units and Measurements. ICRU Report 62. Prescribing, Recording, and Reporting Photon Beam Therapy (Supplement to ICRU Report 50). J ICRU. 1999.
16. Stupp R, Hegi ME, Gorlia T, Erridge SC, Perry J, Hong YK, et al. Cilengitide combined with standard treatment for patients with newly diagnosed glioblastoma with methylated MGMT promoter (CENTRIC EORTC 26071-22072 study): a multicentre, randomised, open-label, phase 3 trial. Lancet Oncol. 2014;15(10):1100-8.
17. Paravati AJ, Heron DE, Landsittel D, Flickinger JC, Mintz A, Chen YF, et al. Radiotherapy and temozolomide for newly diagnosed glioblastoma and anaplastic astrocytoma: Validation of Radiation Therapy Oncology Group-Recursive Partitioning Analysis in the IMRT and temozolomide era. J Neurooncol. 2011;104(1):339-49.
18. Shepard DM, Earl MA, Li XA, Naqvi S, Yu C. Direct aperture optimization: A turnkey solution for step-and-shoot IMRT. Med Phys. 2002;29(6):1007-18.
19. Mayo C, Yorke E, Merchant TE. Radiation Associated Brainstem Injury. Int J Radiat Oncol Biol Phys. 2010; 76(3): 36-41.
20. Emami B, Lyman J, Brown A, Cola L, Goitein M, Munzenrider JE, et al. Tolerance of normal tissue to therapeutic irradiation. Int J Radiat Oncol Biol Phys. 1991;21(1):109-22.
21. Scoccianti S, Detti B, Gadda D, Greto D, Furfaro I, Meacci F, et al. Organs at risk in the brain and their dose-constraints in adults and in children: a radiation oncologist's guide for delineation in everyday practice. Radiother Oncol. 2015 Feb;114(2):230-8.
22. MacDonald SM, Ahmad S, Kachris S, Vogds BJ, DeRouen M, Gittleman AE, et al. Intensity modulated radiation therapy versus three-dimensional conformal radiation therapy for the treatment of high grade glioma: a dosimetric comparison. J Appl Clin Med Phys. 2007;8(2):47-60.
23. Feuvret L, Noël G, Mazeron JJ, Bey P. Conformity index: A review. International Journal of Radiation Oncology Biology Physics. 2006 ;64(2):333-42.
24. Vieillot S, Azria D, Lemanski C, Moscardo CL, Gourgou S, Dubois JB, et al. Plan comparison of volumetric-modulated arc therapy (RapidArc) and conventional intensity-modulated radiation therapy (IMRT) in anal canal cancer. Radiat Oncol. 2010;5:92.
25. Clivio A, Fogliata A, Franzetti-Pellanda A, Nicolini G, Vanetti E, Wyttenbach R, et al. Volumetric-modulated arc radiotherapy for carcinomas of the anal canal: A treatment planning comparison with fixed field IMRT. Radiother Oncol. 2009;92(1):118-24.
26. Ansari S, Satpathy S, Paul S. Dose Distribution Analysis in Rapid Arc and IMRT Radiotherapy Plan in Head and Neck Cancer Using Multiple Parameters. Iranian Journal of Medical Physics. 2018. Doi: 10.22038/ijmp.2018.31896.1378.
27. Bahreyni Toossi MT, Zare H, Eslami Z, Bayani Roodi S, Daneshdoust M, Saeed Z, et al. Assessment of Radiation Dose to the Lens of the Eye and Thyroid of Patients Undergoing Head and Neck Computed Tomography at Five Hospitals in Mashhad, Iran. Iranian Journal of Medical Physics. 2018; 15(4): 226-30.
28. Bush K, Townson R, Zavgorodni S. Monte Carlo simulation of RapidArc radiotherapy delivery. Phys Med Biol. 2008;53(19): 359-70.
29. Wagner D, Christiansen H, Wolff H, Vorwerk H. Radiotherapy of malignant gliomas: Comparison of volumetric single arc technique (RapidArc), dynamic intensity-modulated technique and 3D conformal technique. Radiother Oncol. 2009;93(3):593-6.
30. Shaffer R, Nichol AM, Vollans E, Fong M, Nakano S, Moiseenko V, et al. A Comparison of Volumetric Modulated Arc Therapy and Conventional Intensity-Modulated Radiotherapy for Frontal and Temporal High-Grade Gliomas. Int J Radiat Oncol Biol Phys. 2010;76(4):1177-84.
31. Zach L, Stall B, Ning H, Ondos J, Arora B, Uma S, et al. A dosimetric comparison of four treatment planning methods for high grade glioma. Radiat Oncol. 2009;4(1):45.