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ORIGINAL ARTICLE

Comparative Study of Intensity Modulated Radiotherapy, Volumetric Modulated Arc Therapy versus Three Dimensional Radiotherapy in High Grade Glioma Patients

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ABSTRACT

Background: In contrast to three-dimensional conformal radiotherapy (3DCRT), intensity-modulated radiotherapy (IMRT) improves dose homogeneity, conformity, and target volume coverage while delivering less radiation to normal brain tissue and organs at risk, such as the brainstem, optic chiasma, and brainstem. VMAT is an advanced radiation therapy method that administers radiation continuously while the treatment machine rotates around the patients.

Methods*:* Planning data from 48 patients with high-grade glioma (HGG) were analyzed. The dose distribution for the CTV, PTV, and OAR was compared across three techniques—3D CRT, IMRT, and VMAT—using Dose Volume Histograms (DVHs)

Results*:* We found the PTV coverage in terms of V95% was significantly higher in the VMAT and IMRT plans with values of 99.93 ± 0.12 and 99.49± 0.61 respectively compared to 98.23 ± 0.64 for the 3D-CRT plan

Conclusion: the VMAT technique has proven better capability in reducing the radiation exposure to nearby healthy organs.

Key words:3DCRT; IMRT; VMAT; HGG.

INTRODUCTION

According to the WHO, high-grade glioma (HGG) is the term for Grade III and IV tumors, such as anaplastic astrocytoma (AA), anaplastic oligodendroglioma (AO), and glioblastoma [1]. Among all adult central nervous system (CNS) cancers, glioblastoma multiforme (GBM) is especially prevalent, as it comprises 45 to 50 percent of all gliomas [2]. Research and advancements in related sciences have not solved the fact that GBM remains an aggressive disease, with most patients living for less than one year after diagnosis [3]. The conventional treatment for HGG is maximum surgical resection followed by adjuvant concurrent chemoradiation [4]. The National Comprehensive Cancer Network (NCCN) guidelines for postoperative chemoradiotherapy for HGG recommends a dosage of 60 Gy in 2.0 Gy per fraction or 59.4 Gy over 34 sessions in 1.8 Gy per fraction [5].

In contrast to three-dimensional conformal radiotherapy (3DCRT), intensity-modulated radiotherapy (IMRT) improves dose homogeneity, conformity, and target volume coverage while delivering less radiation to normal brain tissue and organs at risk, such as the brainstem, optic nerves, optic chiasma, and brainstem [6].VMAT is a novel radiation therapy technique that delivers the radiation dose continuously as the treatment machine rotates. The gantry usually rotates the patient once or twice during treatment, but more arcs may be necessary for extra complicated cases [7]. Compared to 3DCRT, VMAT provides superior dose conformity, more homogeneous target coverage, more homogeneous distribution of the dose and improved OAR sparing [8].

The aim of this research is comparing dosimetrically volumetric-modulated arc therapy (VMAT), intensity-modulated radiotherapy (IMRT), and three-dimensional

conformal radiation (3DCRT) in the treatment of HGG.

METHODS

Study Design and Ethical Approval

The current prospective observational study included 48 patients, divided into three groups. Group 1 (n=24) was treated using 3DCRT, Group 2 (n=12) with IMRT, and Group 3 (n=12) was prescribed VMAT. Clinical data were obtained from the medical files at nuclear medicine department Zagazig university hospitals and also from the international medical center, The participants were recruited during the time frame of October 2023 and February 2025. The teamwork did full history, performance status evaluations, patients underwent contrast-enhanced brain MRI. The study followed the ethical principles given in the Declaration of Helsinki. All participants gave their informed consent, and approval was provided by the board of ethics (approval number: 11072-10/10-2023).

Eligibility Criteria

Inclusion criteria: Patients who 1) had histologically confirmed HGG, 2) No brainstem or optic nerve involvement on preoperative MRI, 3) planning target volume (PTV) prescribed at 60 Gy, 4) age between 20 and 75 years, 5) had Karnofsky Performance Status (KPS) scale >60, and 6) written informed consent. Exclusion criteria 1) previous cranial radiotherapy, 2) prior treatment for HGG, 3) pregnancy, suspected pregnancy, or breastfeeding, 4) intention to become pregnant during treatment, 5) KPS <60, 6) presence of psychiatric illness, and 7) any clinical judgment deeming the patient unsuitable for the study.

All patients underwent simulation using thermoplastic mask immobilization. Computed tomography (CT) scans were acquired in 3-mm axial slices from the vertex to the C2 vertebral level. The CT images are imported to the treatment planning system (TPS), Elekta Plan Release 2.12,151204 in 3DCRT and Varian True Beam system equipped with a high-definition multi-leaf collimator in conjunction with Varian's Eclipse Treatment Planning System, version 15.6 in IMRT and VMAT.

Target Volume Delineation and Planning Techniques

Target volumes are Gross total volume (GTV) defined as T1 abnormality + resection cavity, Clinical Target Volume (CTV) is T2 or FLAIR abnormality +2-cm+GTV.PTV1 is CTV+0.5 cm, and PTV2 was GTV+0.5 cm. In 3DCRT, the initial PTV was treated to 46 Gy in 23 fractions. After 46 Gy, the cone down or boost to planning volume will be treated to a total of 60 Gy in 30 fraction. In IMRT and VMAT, treatment delivery was in one phase

PTV1 50/25frs, PTV2 60/25frs

simultaneous integrated boost. 3DCRT beams ranged from 2 to 6 beams with field IMRT dosimetry was analyzed, the receiving Average dose and the OAR dose distribution in the IMRT technique are examined in centiGray (cGy) units, the average dose received in the VMAT technique is examined and treatment plans were made using 2 full arc or 2 half arc technique, depending on the location of the disease, along with the dose distribution in OARs using the i

Plan evaluation

The study team analyzed the dose distribution using the Dose Volume Histogram (DVH) for the Clinical Target Volume (CTV), PTV, and OAR across 3DCRT, IMRT, and VMAT approaches, taking into account the Biological Effective Dose (BED) and equivalent dose at 2Gy (EQD2) to evaluate dosimetric parameters. The dosimetric parameters for target coverage in all plans were designed to ensure that > 95% of the PTV being covered by > 95%isodose line. while adhering to the dose constraints for OARs. Furthermore, hot spots exceeding 110% of the prescribed dosages were confined to less than 20% of the PTV and limited to under 1% outside the PTV. Concerning OARs, the tolerance dosage was defined as the maximum dose (Dmax; ≤54 Gy) for the brainstem, with a point dose of ≤60 Gy if the PTV included the brainstem, ≤54 Gy (Dmax) for the optic nerve, ≤54 Gy (Dmax) for the optic chiasm, a Dmean of the eye ≤50 Gy, and a Dmax for the lens ≤7 Gy, however ≤10 Gy in 3DCRT [9]. The target volume parameters included Dmax, Dmin, and Dmean, whereas the OAR parameters included Dmax, Dmin, Dmean, and D50.

A comparative evaluation of distribution of the dose across the three techniques—3D CRT, IMRT, and VMAT—in high-grade glioma

patients was performed. DVH analysis was used to assess PTV coverage and the preservation of OARs. The quality of coverage was evaluated using RTOG metrics: Coverage Index = Minimal isodose around the target / Reference isodose; and Homogeneity Index = Maximum isodose inside the target / Reference isodose.

Statistical analysis:

The gathered data were inputted and statistically examined using the Statistical Package for Social Sciences (SPSS), version 27.0 (IBM, 2020). Qualitative variables were shown as frequencies and their respective percentages. Quantitative variables were presented as mean ± standard deviation (SD), in addition to median and range. The Shapiro test was used to evaluate the normality of data distribution. The Chi-square test was applied to examine differences between qualitative variables. For normally distributed quantitative data across more than two groups, the ANOVA F-test followed by the post hoc Tukey test was conducted. For cases of non-normally distributed quantitative data, the Kruskal-Wallis test accompanied with post hoc Dunn's test was used to evaluate group differences. A p-value of less than 0.05 was deemed statistically significant, and a p-value of less than 0.001 indicated significant findings.

RESULTS

Data expressed as mean±SD & range or median & range, SD: Standard deviation, ^: ANOVA F test, $: Kruskal Wallis test, Post hoc: Tukey test for F & Dunn's for KW, P1: Group A versus B1, P2: Group A versus B2, P3: Group B1 versus B2, NS: Non significant (P>0.05), *: Significant (P<0.05), **: Highly significant (P<0.001)

Table (1) indicates that there were no statistically significant differences among the study groups for age, sex distribution, tumor site, histology, laterality, or surgical intervention. Table (2) indicated that there were no statistically significant differences among the studied groups regarding performance status, duration between surgery and radiotherapy, initial PTV, PTV2 in CC, PTV 60 max, PTV 60 V90, and Homogeneity index. However, statistically significant differences were observed in PTV 60 D min, PTV 60 V95, PTV 60 V100, and Quality coverage.

Post hoc revealed that in PTV r0 D min there was a statistically significant increase in Group B2 compared to A & B1. A statistically significant reduction in PTV 60 V95 and quality coverage was seen in Group A relative to Groups B1 and B2, while a statistically significant drop in quality coverage was noted in Group B1 compared to Group B2. Additionally, there was a statistically significant reduction in PTV 60 V100 in Group A relative to Group B2.

Table (3) indicated that there were no statistically significant differences in CC among the tested groups in the brain stem, optic chiasma, right and left optic nerves, right and left lenses, brain stem D max, and D50; nevertheless, there were statistically significant differences in all other parameters. Post hoc revealed that there was a statistically significant increase in D mean, D 50 of optic chiasma, right and left optic nerve D 50 and right optic nerve D mean and D max of right lens in Group A compared to B1&2. Also, there was a statistically significant increase in D mean of Brain stem, optic chiasma mean, right and left lens in D mean, max & D 50 in Group B1 compared to B2. Finally, there was a statistically significant increase in optic chiasma D50, Lt optic nerve D50, Rt optic nerve D mean, D 50 and Rt lens D max among Group A compared to B1.

Table 1: Demographic data among the studied groups:

Variable		**Group A (3DCRTH) (*n*=24)**		**Group B1 IMRT (*n*=12)**		**Group B2 VMAT (*n*=12)**		**F**	**P**
Age: (years)	***Mean ± Sd*** ***Range***	**55.33±9.86** **40-70**		**58.75±8.58** **45-68**		**54±10.93** **33-67**		**0.51**	**0.62** **NS**
Variable		**No**	**%**	**No**	**%**	**No**	**%**	**χ^2**	**P**
Age group:	***≤ 60 years*** ***> 60 years***	**14** **10**	**58.3** **41.7**	**5** **7**	**41.7** **58.3**	**7** **5**	**58.3** **41.7**	**1.00**	**0.60** **NS**
Sex:	***Female***	**12**	**50**	**8**	**66.7**	**6**	**50**	**1.01**	**0.60**

Variable		Group A (3DCRTH) (*n*=24)		Group B1 IMRT (*n*=12)		Group B2 VMAT (*n*=12)		F	P
	Male	12	50	4	33.3	6	50		NS
Tumor location:	*Frontal*	4	16.7	1	8.3	2	16.7		
	Fronto-parital	5	20.8	2	16.7	4	33.3		
	Temporal	8	33.3	4	33.3	3	25		
	Parital	3	12.5	2	16.7	1	8.3	2.38	0.99
	Parito-occipital	2	8.3	1	8.3	1	8.3		NS
	Parito-temporal	2	8.3	2	16.7	1	8.3		
Histology:	*Astrocytoma III*	6	25	3	25	0	0	3.69	0.16
	GBM	18	75	9	75	12	100		NS
Laterality:	*Right*	9	37.5	7	58.3	5	41.7	1.44	0.49
	Left	15	62.5	5	41.7	7	58.3		NS
Surgical Intervention:	*Gross total reasction*	3	12.5	2	16.7	4	33.3		
	Subtotal resection	6	25	7	58.3	5	41.7	8.19	0.09
	Biopsy	15	62.5	3	25	3	25		NS

SD: Standard deviation, F: ANOVA test, χ^2: Chi square test, NS: Non significant (P>0.05), *: Significant (P<0.05)

Table 2: Treatment data among the studied groups:

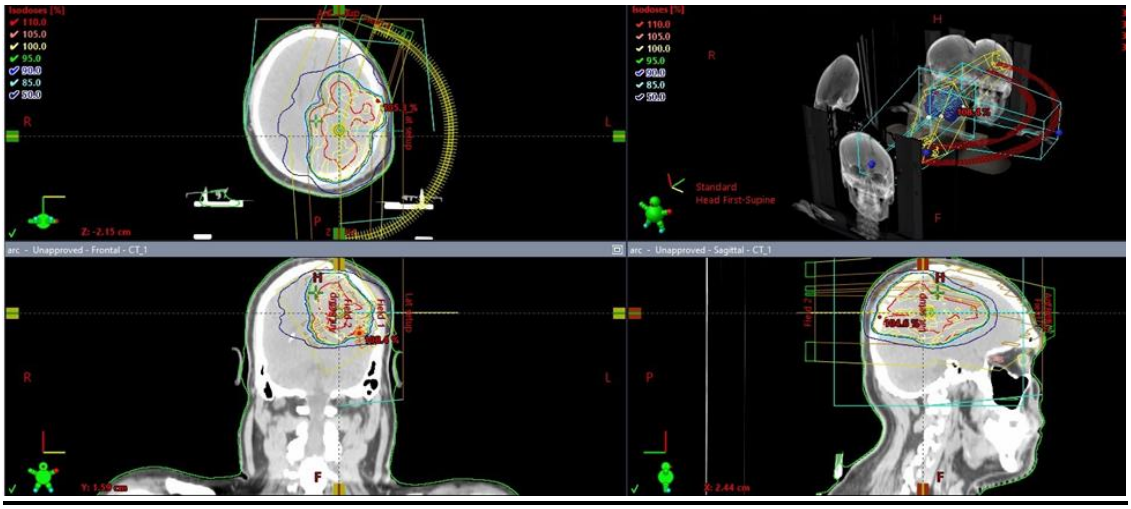
Variable	Group A (3DCRTH) (*n*=24)		Group B1 IMRT (*n*=12)		Group B2 VMAT (*n*=12)		Test	P	Post hoc
	No	%	No	%	No	%			
Performance status:									
KPS 90	4	16.7	3	25	4	33.3	5.67!	0.23	---
KPS 80	5	20.8	5	41.7	5	41.7		NS	
KPS 70	15	62.5	4	33.3	3	25			
Duration between Sur. /RTH: (weeks)	5.08±0.83 4-6		4.5±0.91 3-6		4.58±0.79 4-6		2.53^	0.09 NS	----
Initial PTV in CC:	495.71±145.98 308-735		479.67±17.68 456-510		561.33±68.22 483-710		1.96^	0.15 NS	----
PTV2 in CC:	300.33±111.29 120-454		354.83±78.87 200-447		373.33±96.16 180-516		2.51^	0.09 NS	---
PTV 60 D min: (cGy)	5247.21±179.33 4900-5678		5355.08±130.62 5123-5715		5765.33±39.92 5671-5805		52.04^	<0.001**	0.10 NS[1] <0.001**[2] 0.009*[3]
PTV 60 D max: (cGy)	6363.25±153.14 6100-6576		6261.58±103.04 6137-6377		6433.75±70.49 6195-6405		2.69^	0.08 NS	----
PTV 60 V90: (%)	99.42±0.62 98-100		99.81±0.26 99.2-100		99.65±0.38 99-100		2.64^	0.08 NS	-----
PTV 60 V95: (%)	98.23±0.64 97-99.7		99.49±0.61 97.9-100		99.93±0.12 99.6-100		44.49^	<0.001**	0.01*[1] 0.01*[2] 0.13 NS[3]
PTV 60 V100: (%)	74.83±14.61 50-95		84.08±15.96 50-93		91.58±7.44 71.8-96		6.39^	0.004*	0.14 NS[1] 0.003*[2] 0.38 NS[3]
Homogeneity index:	1.06±0.03 1.01-1.09		1.04±0.02 1.02-1.08		1.05±0.01 1.03-1.06		1.99^	0.15 NS	----
Quality coverage:	0.80±0.08 0.65-0.93		0.86±0.07 0.68-0.9		0.96±0.01 0.94-0.97		21.33^	<0.001 **	0.03*[1] 0.004*[2] 0.01*[3]

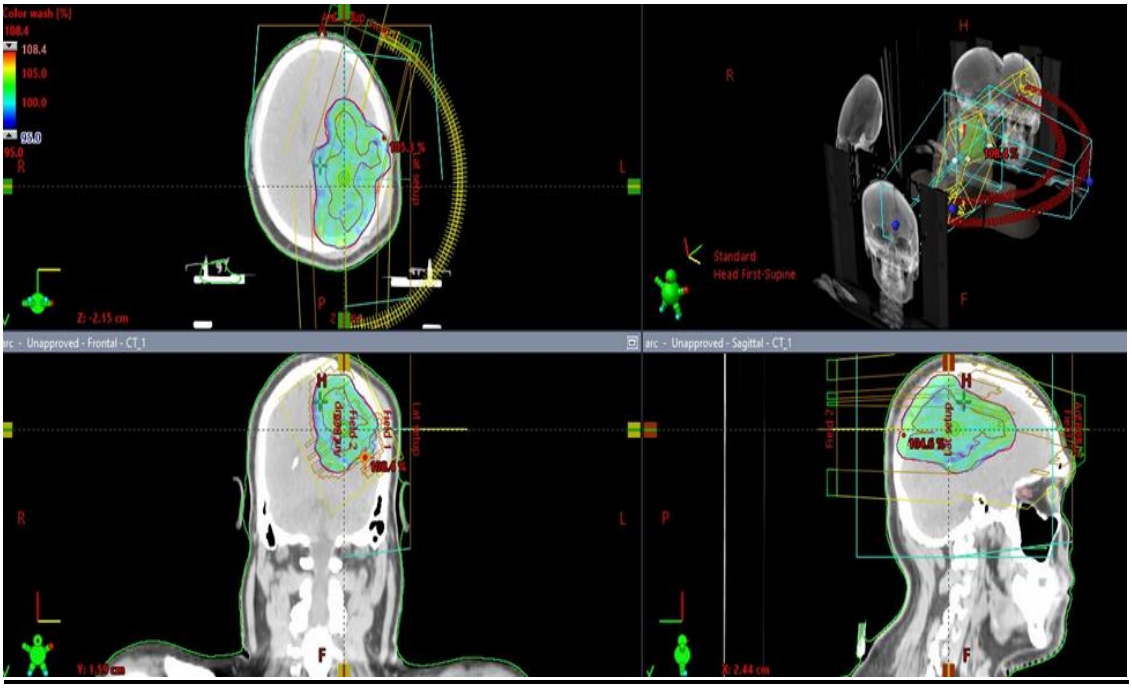
Data expressed as mean±SD & range, !:Chi square test (χ^2), SD: Standard deviation, ^: ANOVA F test, Post hoc: Tukey test, P1: Group A versus B1, P2: Group A versus B2, P3: Group B1 versus B2, NS: Non significant (P>0.05), *: Significant (P<0.05), **: Highly significant (P<0.001)

Table 3: Radiotherapy dose to OAR among the studied groups:

Variable	Group A (3DCRTH) (*n*=24)	Group B1 IMRT (*n*=12)	Group B2 VMAT (*n*=12)	Test	P	Post hoc
Brain stem in CC:	25.54±2.13 22-29	25.74±1.58 24-30	24.67±0.79 24-26.3	1.35^	0.27 NS	----
Brain stem Dmean: (cGy)	2600 1062-4609	2330 962-2634	2010 330-980	9.72$	0.009*	0.22 NS*[1] 0.01*[2] 0.03*[3]
Brain stem D max: (cGy)	5100.04±386.36 2948-5200	4930.25±373 2410-5188	4870±382.95 2390-5070	1.72^	0.20 NS	----
Brain stem D 50: (cGy)	1705.71±381.2 1300-3800	1650.08±300.24 1440-2200	1440.75±398 1200-3100	2.12^	0.13 NS	----
Op chiasma in CC:	0.53±0.11 0.4-0.67	0.54±0.13 0.6-0.9	0.56±0.14 0.3-0.9	0.24^	0.79 NS	-----
Op chiasma D mean: (cGy)	3470 2725-5210	2970 2150-3200	2790 2049-3000	29.12$	<0.001**	<0.001**[1] <0.001**[2] 0.13 NS[3]
Op chiasma D max: (cGy)	4320.83±1314.53 1204-5300	4080.25±1241.1 1109-4907	3810.58±1000.2 2056-4870	3.27^	0.04*	0.46 NS[1] 0.04*[2] 0.48 NS[3]
Op chiasma D 50: (cGy)	2760 700-3800	2230 735-3630	2020 649-3084	6.94$	0.008*	0.02*[1] 0.01*[2] 0.08 NS[3]
Lt optic nerve in CC:	0.27±0.11 0.1-0.4	0.25±0.07 0.1-0.3	0.2±0.07 0.1-0.3	2.29^	0.11 NS	---
Lt optic nerve D mean: (cGy)	500 200-764	475 210-725	300 126-551	5.97$	0.02*	0.16 NS[1] 0.02*[2] 0.04*[3]
Lt optic nerve D max: (cGy)	3240 425-5133	3015 371-4308	2800 336-3567	3.39$	0.04*	0.25 NS[1] 0.04*[2] 0.18 NS[3]
LT optic nerve D50: (cGy)	1797.5 100-3000	1490.5 128.5-2421	1500.5 122-2460	4.29$	0.03*	0.04*[1] 0.03*[2] 0.98 NS[3]
Rt optic nerve in CC	0.26 0.15-0.45	0.25 0.1-0.3	0.24 0.1-0.4	0.19$	0.83 NS	----
Rt optic nerve D mean: (cGy)	1647 191-3101	1496.5 147-2589	1444 132-2463	4.77$	0.01*	0.02*[1] 0.02*[2] 0.71 NS[3]
Rt optic nerve D max: (cGy)	2920 409-5390	2732.5 407-4743	2670 338-4274	3.20$	0.03*	0.08 NS[1] 0.03*[2] 0.54 NS[3]
Rt optic nerve D 50: (cGy)	1600 398-3800	1366 355-1745	1290 320-1662.5	16.45$	0.007*	0.005**[1] 0.003*[2] 0.32 NS[3]
Lt lens in CC	0.2 0.1-0.3	0.10 0.1-0.3	0.2 0.1-0.4	3.12$	0.21 NS	---
Lt lens D mean: (cGy)	500 65-1102	475 30-1149	204.8 20-831.6	28.72$	<0.001**	0.06 NS[1] <0.001**[2] <0.001**[3]
Lt lens D max: (cGy)	676 272-1220	500 333-1063	260.75 123-636	26.78$	<0.001**	0.40 NS[1] <0.001**[2] <0.001**[3]
Lt lens D50: (cGy)	490 33-780	380 44-720	180 20-330	25.37$	<0.001**	0.58 NS[1] <0.001**[2] <0.001**[3]

Rt lens in CC	**0.2** **0.1-0.3**	**0.15** **0.1-0.3**	**0.15** **0.1-0.5**	**4.44$^{\$}$**	**0.11** **NS**	**----**
Rt lens D mean: (cGy)	**295** **71-780**	**232** **24-650**	**190** **20-436**	**14.16$^{\$}$**	**0.002***	**0.25 NS^{1}** **0.002*^{2}** **0.01*^{3}**
Rt lens D max: (cGy)	**399** **87-973**	**300.5** **340-718**	**225.5** **224-542**	**11.91$^{\$}$**	**0.003***	**0.02*^{1}** **0.03*^{2}** **0.01*^{3}**
RT lens D50: (cGy)	**300** **35-490**	**250** **185-389**	**155** **120-236**	**9.54$^{\$}$**	**0.008***	**0.08 NS^{1}** **0.03*^{2}** **0.01*^{3}**





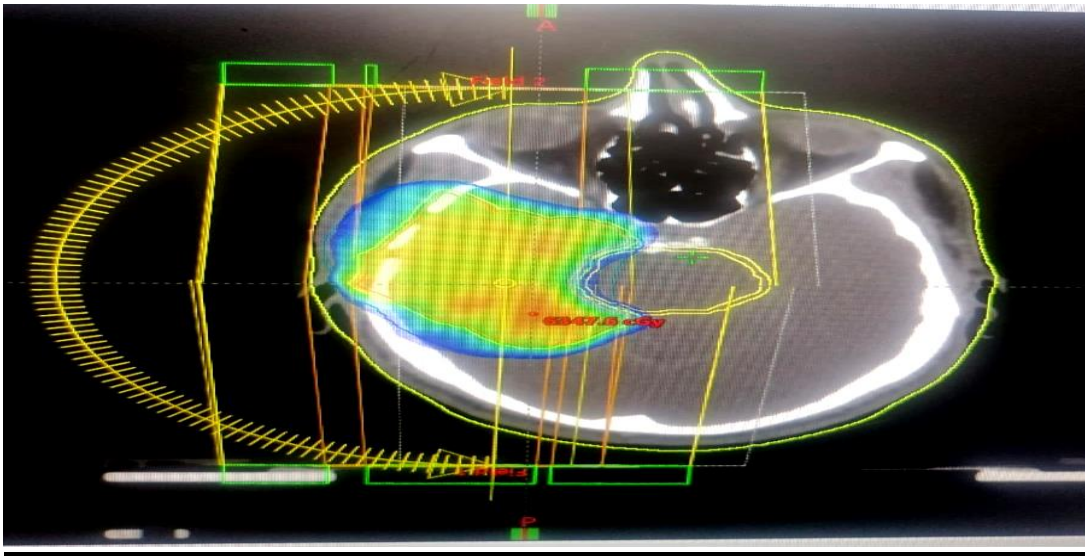


Figure 1; A, B and C of VMAT plan

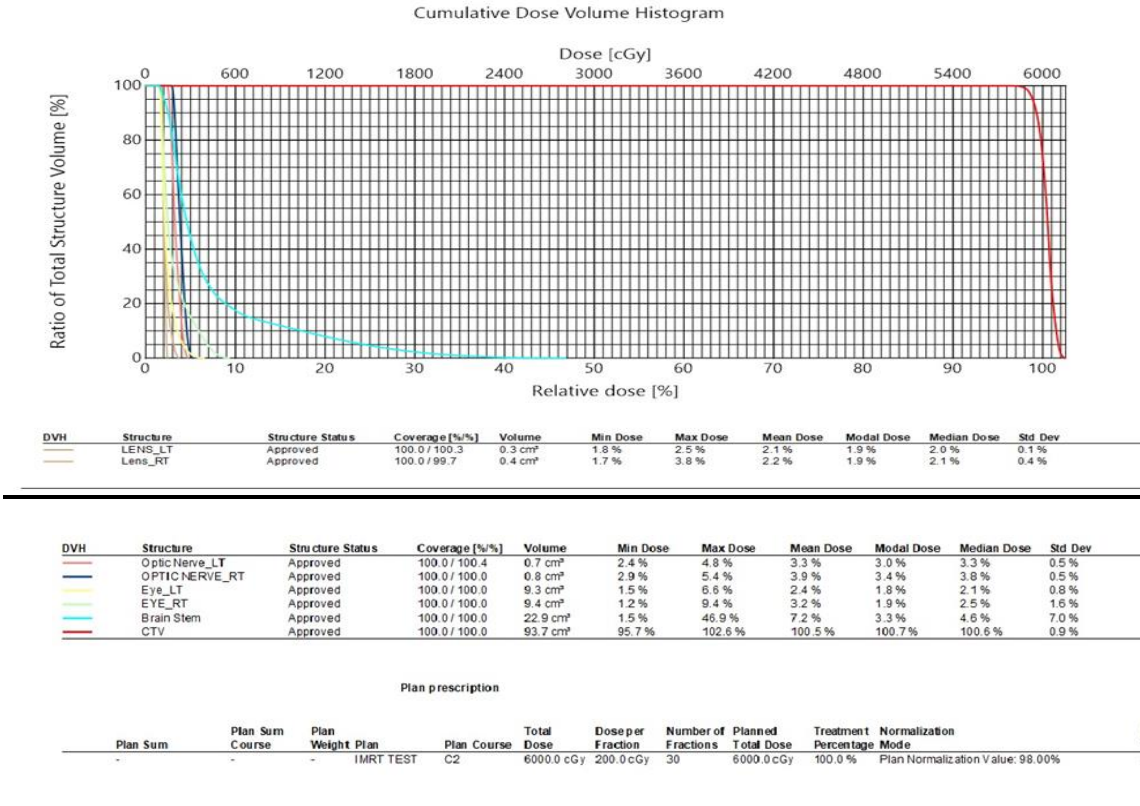


Figure 2: DVH of IMRT Plan

DISCUSSION

This study concludes that the radiation doses delivered to OARs using 3D-CRT, IMRT, and VMAT are within safe limits and significantly contribute to the quality of glioblastoma radiotherapy. These findings are supported by the fact that the doses to surrounding healthy organs remain below established tolerance thresholds. Additionally, doses to the PTV consistently fall within 95%–107% of the limits recommended by the International Commission on Radiation Units and Measurements (ICRU). A comparative dosimetric evaluation was conducted to assess dose distribution across 3D-CRT, IMRT, and VMAT in glioblastoma cases, aiming to identify the most optimal distribution regarding average PTV and OAR doses. VMAT and IMRT plans demonstrated significantly higher PTV coverage, as measured by V95%, with values of 99.93 ± 0.12 and 99.49 ± 0.61, respectively, compared to 98.23 ± 0.64 for 3D-CRT ($p = 0.01$). Additionally, D_max and D_min were greater in the VMAT plans. D_max values were 64.33Gy ± 0.7 (VMAT), 62.61Gy ± 1.03 (IMRT), and 63.63Gy ± 1.53 (3D-CRT) ($p = 0.08$, not significant). D_min was recorded as 57.65Gy ± 0.39 (VMAT), 53.55Gy ± 1.3 (IMRT), and 52.47Gy ± 1.79 (3D-CRT), with p-values indicating statistical significance

between 3D-CRT and VMAT (<0.001), IMRT and VMAT (0.009), and a non-significant result between 3D-CRT and IMRT (0.10). Homogeneity index values—1.05 ± 0.01 (VMAT), 1.04 ± 0.02 (IMRT), and 1.06 ± 0.03 (3D-CRT)—showed no significant difference (p = 0.15). Overall, OAR doses were lowest with VMAT, with statistically significant differences. Post hoc analysis showed increased D_mean to the optic chiasma, right optic nerve, and D_max to the right lens in Group A (3D-CRT) compared to Groups B1 and B2 (IMRT and VMAT). Furthermore, Group B1 (IMRT) had a significantly higher D_mean to the brainstem, optic chiasma, and both lenses than B2 (VMAT). Significant increases in D_mean to the right optic nerve and D_max to the right lens were also noted in Group A compared to Group B1. These findings suggest VMAT offers superior PTV coverage and the lowest OAR exposure, with 3D-CRT exhibiting the highest OAR doses.

In support of these findings, Mashhour et al. reported significantly better PTV coverage in RapidArc (RA) plans, with V95% at 98.4 ± 1.7 versus 94.4 ± 2.6 in 3D-CRT (p = 0.004). Hot spot analysis revealed that V107% was substantially higher in 3D-CRT (10.5 cm^3 ± 0.04) compared to 1.18 cm^3 ± 1.15 in RA plans (p = 0.03). Further comparisons showed higher D_max, D_min, and D_mean values in RA. D_max was 63.7Gy ± 1.9 (RA) versus 60.12Gy ± 2.2 (3D-CRT) (p = 0.014). D_min was 58.5Gy ± 1.5 (RA) versus 56.8Gy ± 2.2 (3D-CRT) (p = 0.321). D_mean was significantly higher in RA (61.8Gy ± 2.3) than in 3D-CRT (58.5Gy ± 1.9) (p = 0.050). The Homogeneity index favored RA (1.9Gy ± 0.123) over 3D-CRT (2.3Gy ± 0.120), though not significantly (p = 0.113). OAR doses were generally lower in RA than in 3D-CRT, except for the intraocular lenses, which had higher doses in RA (ipsilateral lens D_max: 2.9Gy in RA vs 2.7Gy in 3D-CRT, p = 0.002; contralateral lens D_max: 1.6Gy in RA vs 1.5Gy in 3D-CRT, p = 0.001) [8]. Contrasting with our study, VMAT demonstrated lower lens doses than 3D-CRT (left lens D_max: 2.60Gy in VMAT vs 6.76Gy in 3D-CRT, p < 0.001; right lens D_max: 2.25Gy in VMAT vs 3.99Gy in 3D-CRT, p < 0.01).

Hamzah et al. delivered a total dose of 59.4 Gy to the PTV in 33 fractions (1.8 Gy/fraction). They concluded that VMAT yielded the most favorable dose distribution across PTV, CTV, and OARs compared to IMRT and 3D-CRT. VMAT produced higher PTV dose coverage while reducing OAR doses (brainstem, eye, lens, optic nerve). In their findings, the highest OAR dose was to the left optic nerve (4395.7 cGy) and the lowest to the left lens (788.8 cGy) [10].

Singh et al. performed a dosimetric comparison between 3D-CRT and VMAT, showing improved target volume coverage and better OAR sparing with VMAT. The degree of OAR sparing, however, was dependent on tumor proximity and overlap with critical structures. Despite these challenges, VMAT offered better conformity and reduced dose spillage without significantly increasing monitor units (MUs). This technique thus enhances the therapeutic ratio in HGG treatment. However, in specific anatomical configurations, 3D-CRT offered benefits, such as fewer MUs and reduced low-dose exposure to structures like the eyes and lenses (right lens D_mean: 4.37Gy in 3D-CRT vs. 7.24Gy in VMAT, p = 0.125; left lens D_mean: 3.34Gy in 3D-CRT vs. 6.50Gy in VMAT, p = 0.035; right eye D_mean: 6.80Gy in 3D-CRT vs. 9.61Gy in VMAT, p = 0.156; left eye D_mean: 3.34Gy in 3D-CRT vs. 6.50Gy in VMAT, p = 0.035) [11]. This differs from our results, where lens doses were lower in VMAT than 3D-CRT (left lens D_mean: 2.04Gy in VMAT vs 5Gy in 3D-CRT, p < 0.001; right lens D_mean: 1.90Gy in VMAT vs 2.95Gy in 3D-CRT, p = 0.01). These discrepancies could stem from differences in arc design and tumor localization.

Navarria et al. assessed 341 HGG patients and compared 3D-CRT and VMAT. Their definition of GTV included post-operative cavities and T1-enhancing lesions, with CTV and PTV margins of 1 cm and 0.3 cm, respectively. Their results showed that VMAT provided superior clinical and dosimetric performance, aligning with our study's finding of better PTV coverage and dose homogeneity with VMAT [12].

Briere et al. conducted a comparison of IMRT and VMAT in the context of high-grade gliomas. The GTV was derived using T1 MRI

contrast enhancement, including a 2 cm margin for CTV and a 0.5 cm margin for PTV. Comparable PTV coverage, conformance, and homogeneity were observed across IMRT and VMAT. VMAT was linked to markedly decreased mean and maximum doses to the retina, lenses, and contralateral optic nerve [13]. Davidson et al. conducted a comparison of IMRT with single-arc VMAT in 12 glioblastoma patients, revealing comparable dosimetric metrics between the two modalities, but VMAT provided expedited treatment durations [14].

In conclusion, our findings support the superiority of VMAT in reducing radiation exposure to OARs. Therefore, selecting an optimal radiotherapy technique that ensures maximal target coverage and minimal OAR exposure is vital to improving survival outcomes with acceptable toxicity. VMAT also allows for more efficient treatment delivery with greater precision. Given its practical application and radiobiological advantages, VMAT may be the most favorable modality for treating glioblastoma. Future clinical trials with larger patient populations are encouraged to confirm these benefits and potentially establish arc-based delivery as a standard for managing HGGs in challenging anatomical regions [15].

CONCLUSION

The outcome analysis using dose-volume histograms (DVH) and isodose curves proves that 3DCRT, IMRT, and VMAT techniques do not deliver a high radiation dose to nearby organs at risk (OAR). The VMAT technique offers lower irradiation to organs at risk but gives a higher average dose to the target area than IMRT and 3DCRT. It is recommended that VMAT be associated with a better pattern of radiation doses than the other two methods. Given the Above mentioned outcomes, VMAT is widely preferred for treating glioblastoma since it protects OAR from radiation better than IMRT and 3DCRT. In addition, because VMAT uses coplanar beams and decreases the number of beams compared to other techniques, treatment takes less time. Rapid completion of multiple treatments might boost clinical results, and it is especially valuable for those who find it hard to tolerate wearing the mask during extended sessions.

Authors' contributions:

A.H.H, N.G.E, A.A.O and A.E: "Study design; data acquisition; data analysis and interpretation; drafting and critical reviewing of the manuscript. All authors read and approved the final manuscript version and agreed with all parts of the work in ensuring that any queries about the accuracy or integrity of any component of the work are appropriately investigated and handled".

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