IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 21, Issue 4 Ser.5 (April. 2022), PP 26-34
www.iosrjournals.org

Brain Saving Radiotherapy in Skull Metastases using Volumetric Modulated Arc Technique: A Dosimetric Analysis

G.S. Gautam, V.B.Rathore, R.R.Jain, P. Kushwaha, V. Choudhary, V. K. Mishra, M. Beck and R.S.Singh
(Department of Radiotherapy, Pt.J.N.M.Medical College and Regional Cancer Centre, Raipur, India)

Abstract:
Background*: Superiority of Rapid Arc treatment over any other treatment technique reported herewith outer ring structure irradiation of skull. Conventional, 3DCRT, IMRT, Rapid Arc(VMAT) and others new radiotherapy techniques are explored time by time but in case of Skull irradiation due to complex structure of Skull ring as a round shape, Conventional and 3DCRT techniques does not provide proper dose distribution as well as deposit more radiation dose to other parts of the brain. Hence, we have excluded conventional and 3D Conformal technique and explored the brain saving radiotherapy techniques in skull bone irradiation. In present study IMRT and Rapid Arc plan were generated. IMRT plans were made comparable with Rapid Arc treatment plans of outer ring of skull with respect to Conformity and Homogeneity of target and minimizing dose to brain and other limiting structure. It is found that in this type of cases the better and uniform distribution of dose with higher HI value is achieved by employing Rapid Arc technique compared to IMRT technique.*

Materials and Methods*: In the present study 10 patients were selected, breast cancer is most common primary tumour among them followed by lung cancer prostate cancer, malignant Lymphoma and others patients. 21 field IMRT plans were generated and isocentre of field placement is done at centre of brain. The field size adjustment was done to covers entire area of skull. In same patient data Rapid Arc plan was generated with two full arcs clockwise (CW) and anti- clockwise (ACW). Isocentre of arc was placed at centre of brain and field size was adjusted to cover entire skull. Both IMRT and Rapid arc plans were calculated for each cases of Skull bone metastases and dosimetric comparison was made on the bases of conformity and homogeneity of target as well as mean/maximum dose to limiting structure. Our main aim was to reduce mean dose to brain and other limiting structure as well full dose to skull bone with maximum coverage. Among all one particular case outer ring of approximate thickness 1.3 cm of PTV skull is depicted in Figure -1. First Dose Plan was made by employing IMRT technique for treating this PTV. Similarly new dose Plans for irradiation of same PTV were made employing Rapid Arc techniques and the final outcomes were evaluated.*

Result: *Dose Homogeneity was found in the range from 1.19 To 1.22 for IMRT plan and 1.09 to 1.18 for Rapid Arc plan in PTV volume (Tumour). Dose conformity in PTV was achieved in the range from 0.74 to 0.86 for IMRT plan and 0.89 to 0.97 for Rapid Arc plan. The value of Homogeneity Index (HI) and Conformity Index (CI) was close to unity for Rapid Arc plan as compared to IMRT plan. The maximum dose to critical structures was less for Rapid Arc plan than IMRT plan.*

Conclusion: *It was observed that with IMRT technique PTV was not getting radiation dose uniformly distribution, However in Rapid Arc plan more than 95% dose coverage was uniformly achieved in PTV ring and also outline boundary of 95% dose colourwash follows the shape finely same as PTV-ring. Isodose distribution comparison between IMRT and Rapid Arc plan reveals that the Rapid Arc plan provides more uniform dose coverage as compared to IMRT plan and also provides less spillage to the whole brain area. Dose Homogeneity and Dose Conformity Index was close to unity for Rapid Arc plan as compared to IMRT plan. The maximum dose to critical structures was less for Rapid Arc plan than IMRT plan. So, it was concluded the Rapid Arc treatment (VMAT) shows better dose coverage and less dose to critical organ as compared to IMRT plan is suitable for skull bone metastases irradiation.*

Key Word*: Rapid Arc; Skull; Homogeneity Index; Conformity Index; Radiation Therapy.*

Date of Submission: 02-04-2022 Date of Acceptance: 15-04-2022

I. Introduction

The skull metastases were consisting malignant bone tumors and cranium was the site of blood borne metastases of various malignancies. Various malignancies like carcinoma of lung, breast, thyroid, renal cell carcinoma and malignant melanoma leads to blood born metastases mainly at cranium site. Skull metastases are malignant bone tumor and can cause clinical syndromes including pain and other systemic malignancies. Symptoms are manageable but early diagnosis is crucial for selecting treatment.

The metastases may be classified simply in three categories according to location (calvarial or cranium base), distribution in plane (circumscribed or diffused) and invasion (Skull or Scalp). Breast Cancer, Lung Cancer, Prostate Cancer, Malignant Myeloma are mainly primary sites contributes 80% metastases and 20% others. Calvarial circumscribed intraosseous lesions are most common skull bone metastases in both breast and lung cancer whereas, calvarial diffuse invasive lesions are second most common skull bone metastases in Lung cancer and calvarial circumscribed invasive metastases cause local pain and swelling and calvarial diffuse invasive metastases suffered from headache and nausea due to dural and subdural invasion.

The breast cancer is the most frequent source of Skull metastases both for calvarial metastases and for skull base metastases. Calvarial metastases may cause superficial focal pain and cosmetic problem and once calvarial metastases invade into the dura and intradural space, patient suffer from increased intracranial pressure, meningeal irritation and focal neurological signs. The skull base metastases usually cause various combination of cranial nerve signs. Here Radiotherapy, Chemotherapy, Surgery, endocrinological therapy used for patient with skull metastases.

Nowadays with the development of accurate delivery of radiation dose to patient new techniques are invented by the time by time for example brachytherapy and delivery of high energy radiation through conformal IMRT, IGRT, Rapid Arc techniques. These techniques are making feasibility of radiation delivery with more and more accuracy for lethal dose delivery to tumor and the same time sparing the surrounding critical organs which is main aim of radiotherapy. Radiotherapy is the only therapeutic choice for Skull metastases and in sebaceous scalp carcinoma and when surgery is not recommended, such as in cases with severe skull and brain lesions or due to cosmetic and reconstructive complications, or when the patient is unable to undergo surgery [1]. However, due to the concave shape and the proximity to critical structures, it is technically difficult to supply radiation to the complete skull or scalp. Due to its high surface doses and the dispersion of electrons on oblique surfaces, electron beams have historically been selected, but stationary electron-beam fields can create undesirable hotspots in field junctions [2,3]. The use of lateral opposite photon fields combined with lateral electron fields and the movement of the junction during treatment are effective methods to improve dose uniformity at the junction. Electron and photon beam combinations demonstrate higher dose uniformity than electron beams alone. However, the dose distribution is inhomogeneous at the junction of the radiation fields [4]. For complete skull irradiation with the ability to achieve concave dose delivery, intensity modulated radiation therapy (IMRT) is ideally feasible. It has been shown that fixed beam IMRT can increase the coverage and homogeneity of the target dose compared to 3D-CRT. Nevertheless, the volume of the brain irradiated at high doses is decreased at the cost of greater volumes of the brain irradiated at lower doses [5].

A rotational delivery technique, called volumetric arc therapy (VMAT) or Rapid Arc, was recently recorded for complete rotation during irradiation by Kelly et al [6]. Rapid Arc is the recent development in case of radiation dose delivery which seems to be superior than any other technique excluding brachy-therapy which is the localized low energy radiation delivery. Rapid Arc provides much better dose conformity with coplanar rapid Arc than 21-field IMRT by using case-individualized collimator angle settings. This outcome could indicate that rapid Arc could provide a more promising solution for complete skull radiotherapy over fixed-beam IMRT. Lozano et. al reported VMAT for a recurrent basal cell carcinoma of total scalp or skull irradiation [7]. The outcome indicate that Rapid Arc was superior in dose conformity and homogeneity as compared to other modality and requires less complex planning and permits a more reproducible setup. However, there is an inhomogeneous distribution of the dose at the junction of the radiation fields.

Several researchers have investigated approaches such as intensity-modulated radiation therapy (IMRT), Volume-Modulated Arc Therapy (VMAT) and Helical Tomotherapy (HT) to solve this issue. Ostheimer et al. found that in coverage, homogeneity and sparing of OAR, coplanar VMAT plans were marginally superior to non-coplanar IMRT plans [8]. Hu et al. found that there was a lower brain dose associated with non-coplanar VMAT plans than with coplanar VMAT plans [9]. Song et al. reported that Helical Tomotherapy plans showed greater coverage and homogeneity and longer treatment time than coplanar VMAT plans and that normal brain tissue received a lower dose of the former than the latter plans [10].

Current study reported volumetric arc therapy (VMAT) or rapid arc for total skull irradiation using two arcs. In this case with 6MV high energy radiation dose delivery to outer ring of Skull-PTV was considered for dictating betterness of techniques of radiation delivery.

II. Materials And Methods

In a present Study 10 Patient were taken for skull irradiation. Prescribed dose for radiation therapy treatment were 50Gy. Fractionation scheme for this treatment was scheduled for 2Gy per fraction daily and 5 fractions weekly. Patients were immobilized with 3point thermoplastic mould on CT Couch in supine position to achieve positional accuracy. Patient position and marking was done with fiducial marker in thermoplastic mould on CT indexed couch all in one (AIO) base plate. Computed Tomography (CT) images were acquired for head region using Brilliance Big-Bore CT simulator (Philips Medical System, USA). Slice thickness 3 mm was selected to acquire CT images for delineation of target and critical structure more accurately. PTV Skull is delineated in each slice thickness, other structure Brain, Brainstem, Eye Optic Nerve and Pituitary Gland were also contoured. One particular case of outer ring of approximate thickness 1.3 cm of skull depicted as PTV in figure-1. First Dose Plan was made with IMRT technique. 21 fields IMRT plan was generated for treating this PTV with isocentre at the centre of brain. Dose Plans for irradiation of same PTV were generated with Rapid Arc techniques using 2 arcs with same isocentre. Dose Volume Optimization Algorithm PRO- 3 is used for fluence optimization and AAA Algorithm was used for dose calculation for both technique. Here, figure-1shows the delineated target structure (PTV-ring) and figure-2 shows the delineated critical structure. Figure-3 shows the beam arrangement and isocentre placement of radiation treatment field for IMRT technique. Figure-4 shows the optimization of dose objectives and dose volume histogram (DVH) of the treatment plan.

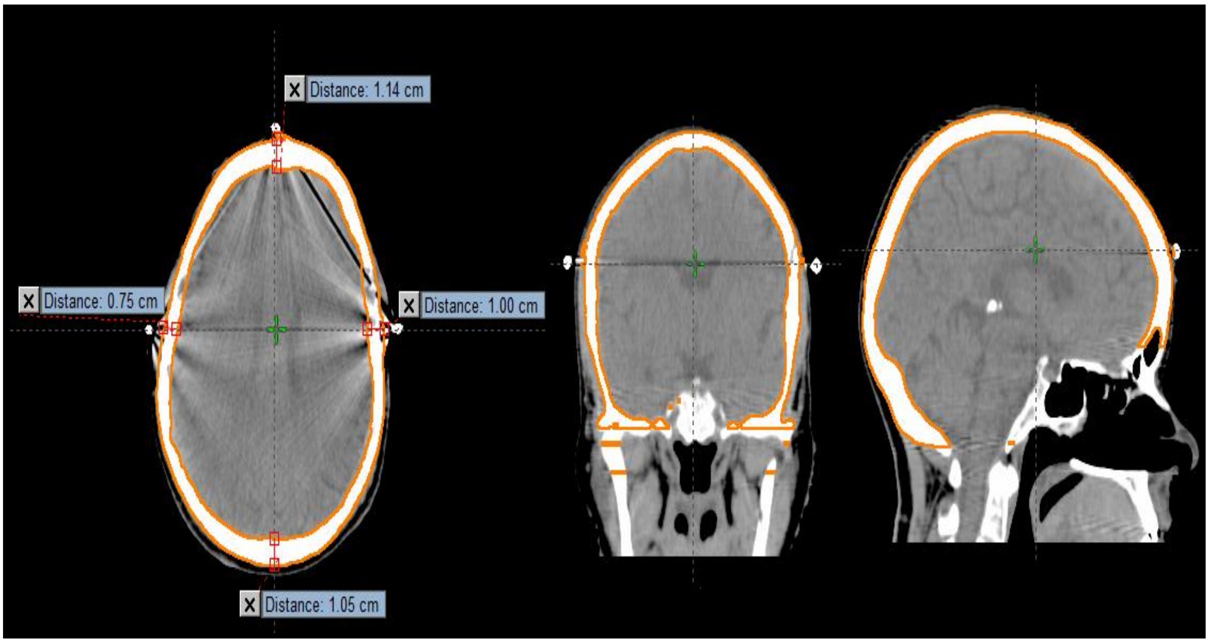


Figure-1Showsthe delineate target structure

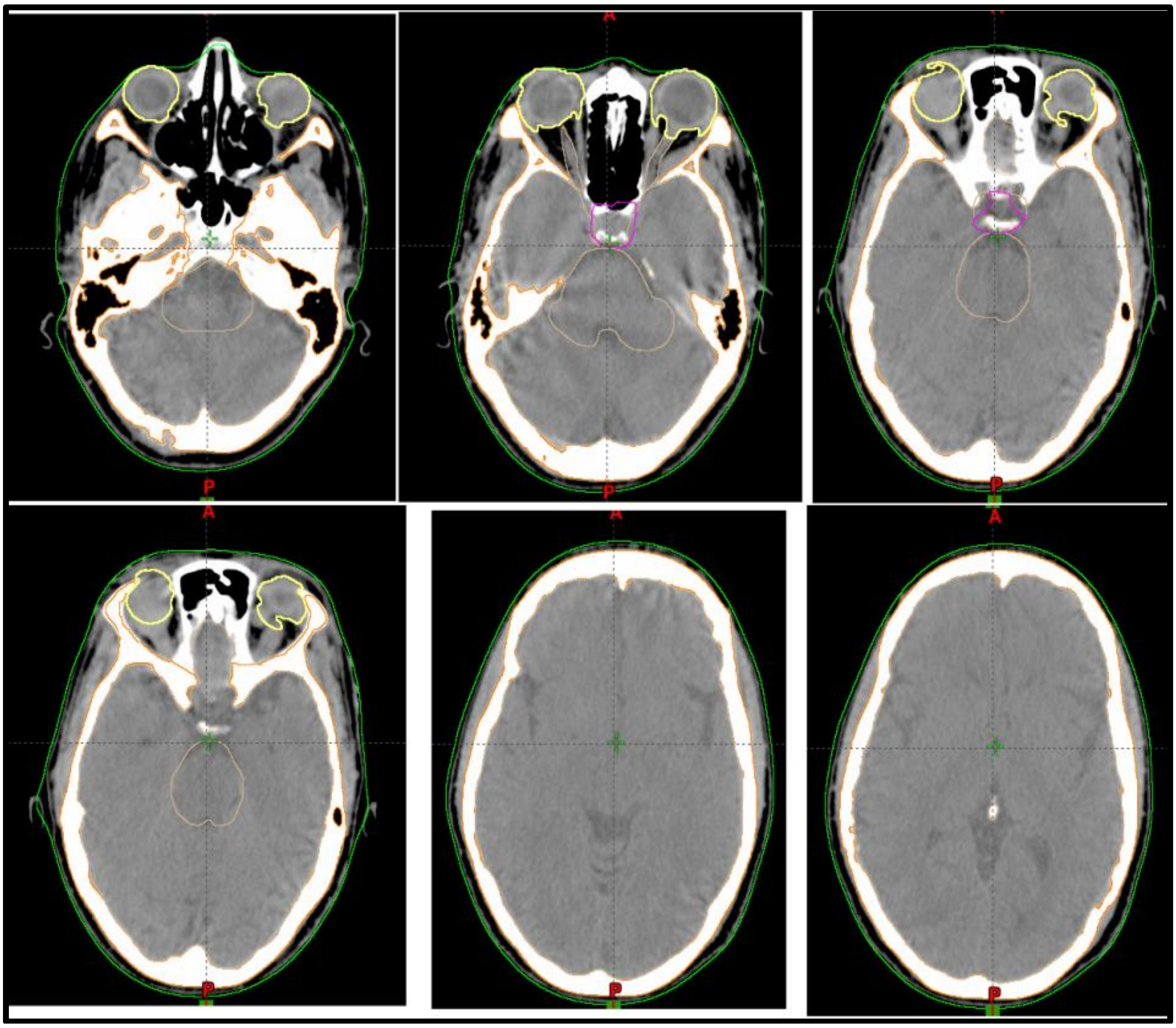


Figure-2Showsthe delineate target and critical structure

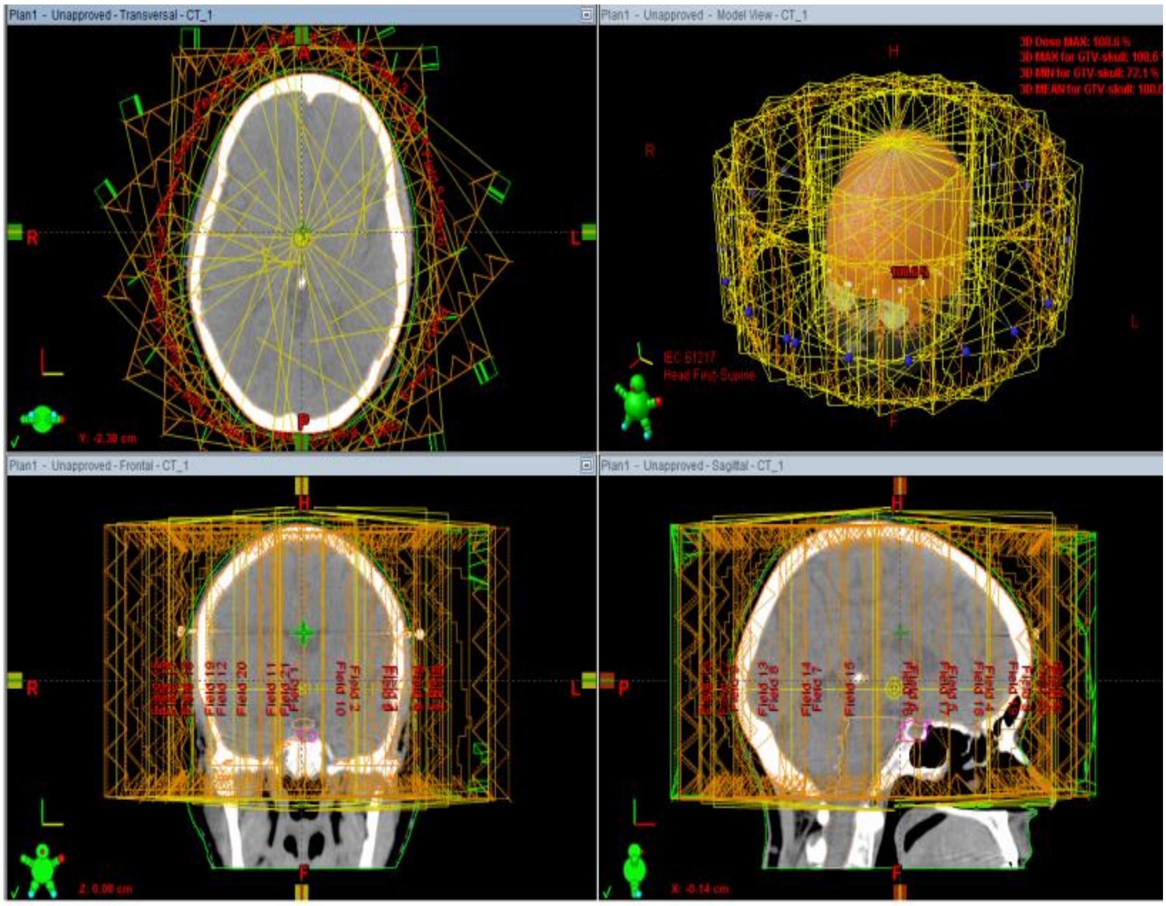
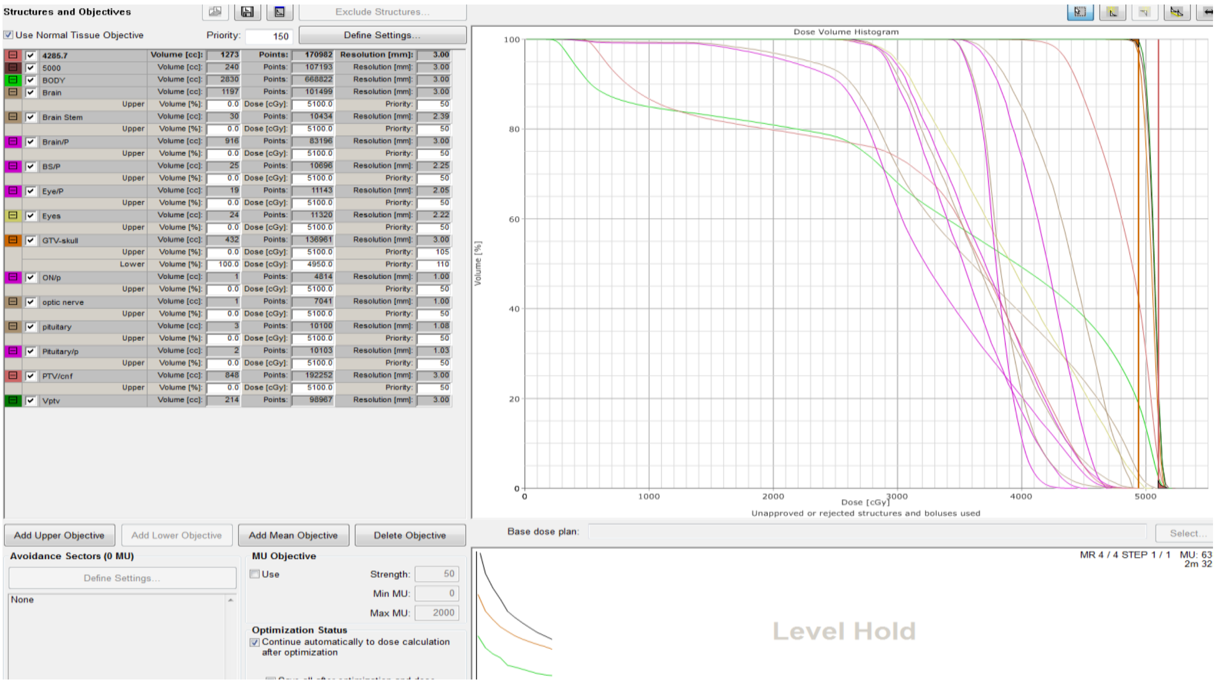


Figure-3Showsthe beam arrangement and iso-Centre placement of radiation treatment field



☑ Use Normal Tissue Objective Priority: 150

☑ 4285.7	Volume [cc]:	1273	Points:	170982	Resolution [mm]:	3.00
☑ 5000	Volume [cc]:	240	Points:	107193	Resolution [mm]:	3.00
☑ BODY	Volume [cc]:	2830	Points:	668822	Resolution [mm]:	3.00
☑ Brain	Volume [cc]:	1197	Points:	101499	Resolution [mm]:	3.00
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ Brain Stem	Volume [cc]:	30	Points:	10434	Resolution [mm]:	2.39
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ Brain/P	Volume [cc]:	916	Points:	83196	Resolution [mm]:	3.00
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ BS/P	Volume [cc]:	25	Points:	10696	Resolution [mm]:	2.25
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ Eye/P	Volume [cc]:	19	Points:	11143	Resolution [mm]:	2.05
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ Eyes	Volume [cc]:	24	Points:	11320	Resolution [mm]:	2.22
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ GTV-skull	Volume [cc]:	432	Points:	136961	Resolution [mm]:	3.00
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	105
Lower	Volume [%]:	100.0	Dose [cGy]:	4950.0	Priority:	110
☑ ON/p	Volume [cc]:	1	Points:	4814	Resolution [mm]:	1.00
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ optic nerve	Volume [cc]:	1	Points:	7041	Resolution [mm]:	1.00
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ pituitary	Volume [cc]:	3	Points:	10100	Resolution [mm]:	1.08
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ Pituitary/p	Volume [cc]:	2	Points:	10103	Resolution [mm]:	1.03
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ PTV/cnf	Volume [cc]:	848	Points:	192252	Resolution [mm]:	3.00
Upper	Volume [%]:	0.0	Dose [cGy]:	5100.0	Priority:	50
☑ Vptv	Volume [cc]:	214	Points:	98967	Resolution [mm]:	3.00

Avoidance Sectors (0 MU)
None

MU Objective
☐ Use
Strength: 50
Min MU: 0
Max MU: 2000

Optimization Status
☑ Continue automatically to dose calculation after optimization

MR 4 / 4 STEP 1 / 1 MU: 63
2m 32

Figure-4 Shows optimization of dose objectives and dose volume histogram (DVH) prepared plan

III. Result

Figure-5 shows the isodose distribution using Intensity Modulated Radiation Therapy (IMRT) plan. It was observed that with IMRT technique PTV was not covering radiation dose with uniform distribution, however, in Rapid Arc plan more than 95% dose coverage was uniformly achieved in PTV ring as shown in

Figure-6. Outline boundary of 95% dose color wash follows the shapes finally same as PTV-ring. Figure-7 shows the isodose distribution comparison between IMRT and Rapid Arc plan. Rapid Arc plan provides more uniform dose coverage as compared to IMRT plan and also provides less spillage to the whole brain area.

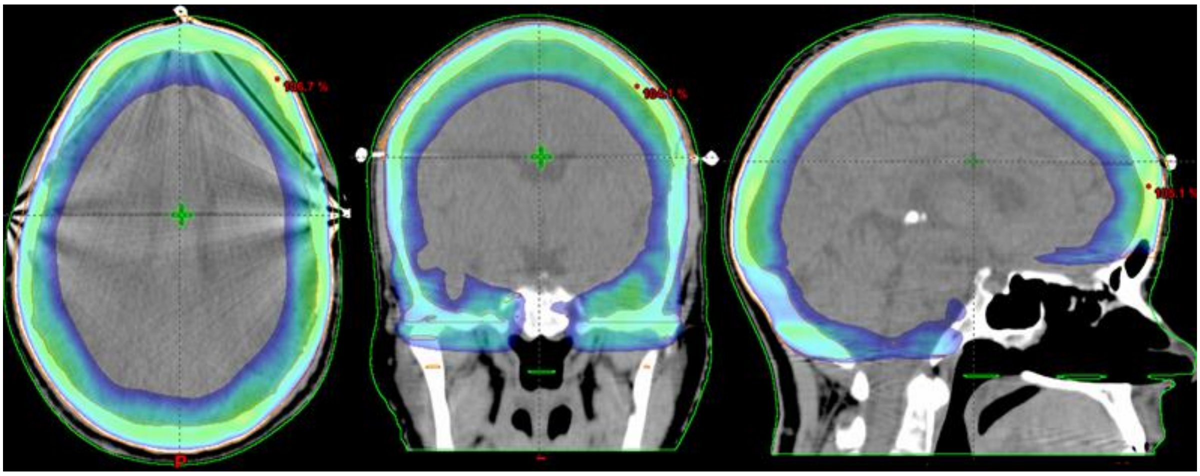


Figure-5 Shows the isodose distribution using intensity modulated radiation therapy (IMRT) plan

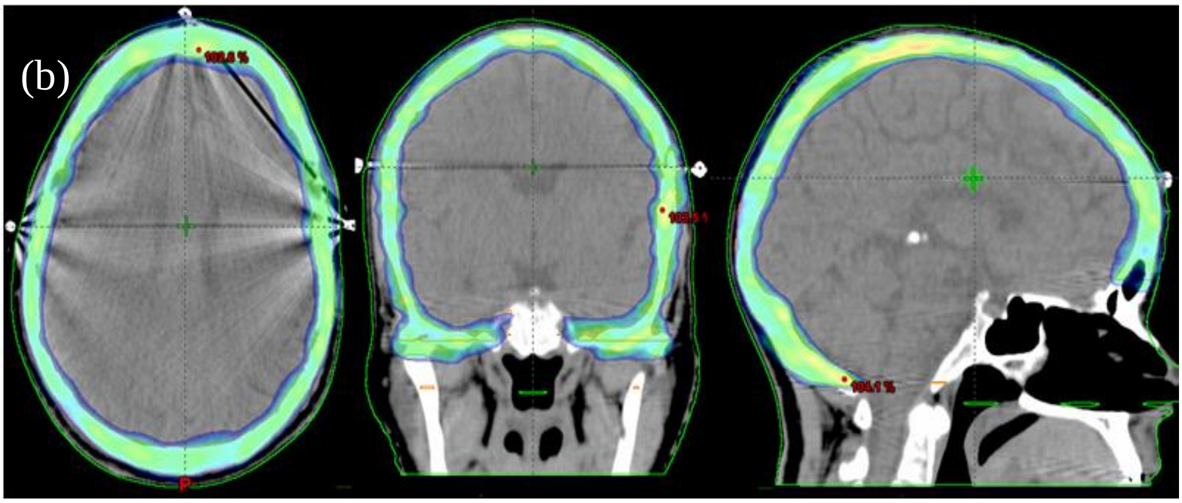


Figure-6 Shows the isodose distribution using Volume-Modulated Arc Therapy (Rapid Arc Plan)

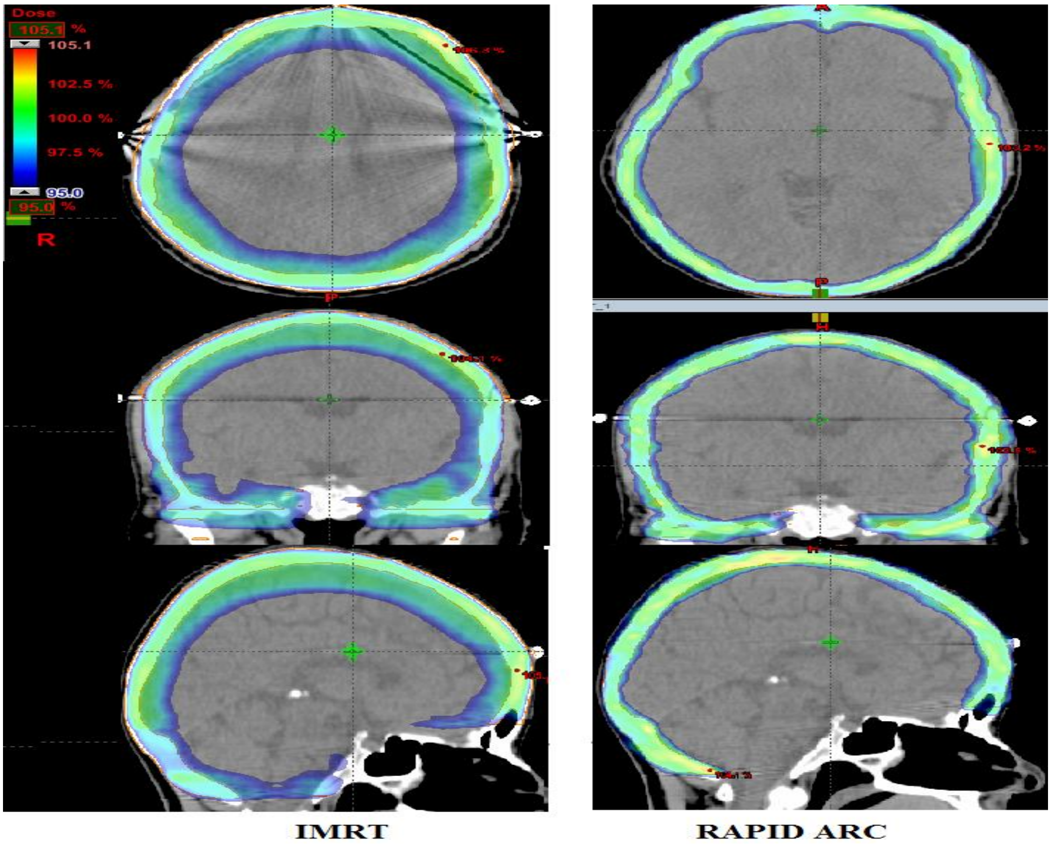


Figure-7 Shows the isodose distribution comparison between IMRT and Rapid Arc Plan

Radiation Plan is evaluated using Dose Homogeneity and Dose Conformity in tumour target. Homogeneity Index (HI) and Conformity Index (CI) was calculated using following formula shown in equation 1 and 2.

$$\mathrm{HI} = \frac{\mathrm{D}_5}{\mathrm{D95}} \qquad (1)$$

$$\mathrm{CI} = \frac{(\mathrm{V}_{95\%}\ \mathrm{DVH\ OF\ PTV})^2}{\mathrm{TV} * \mathrm{V}_{95\%}\ \mathrm{isodose\ line}} \qquad (2)$$

Where - D_5- dose cover 5% of the target volume
D_{95}- doses cover 95% of the target volume
$V_{95\%}$DVH - volume covered by 95% of DVH target volume
$V_{95\%}$ Isodose - volume covered by 95% of isodose line

Dose Homogeneity Index was found in the range from 1.19 To 1.22 for IMRT plan and 1.09 to 1.18 for Rapid Arc plan in PTV volume (Tumour). Dose Conformity in PTV (Tumour) was achieved in the range from 0.74 to 0.86 for IMRT plan and 0.89 to 0.97 for Rapid Arc plan. Case wise evaluation of Dose Index with PTV Volume is tabulated in Table 1. As table 1 shows the value of HI and CI was close to unity for Rapid Arc plan as compared to IMRT plan. The maximum dose to critical structures calculated for IMRT and Rapid Arc plan are mentioned and compared in Table 2. The data revealed that the maximum dose to critical organ was less for Rapid Arc plan than IMRT plan.

Table 1.Shows Homogeneity Index and Conformity Index value calculated for IMRT and Rapid Arc Plan

S. No.	Primary Carcinoma and Prescribed dose		Homogeneity and Conformity Index			
			IMRT		Rapid Arc (VMAT)	
	Primary Site of Carcinoma	Prescribed dose (Dp)	HI	CI	HI	CI
1	Ca Breast	5000	1.21	0.78	1.09	0.97
2	Ca Breast	5000	1.20	0.74	1.09	0.94
3	Ca Breast	5000	1.21	0.79	1.13	0.95
4	Small Cell Ca Lung	2800	1.20	0.75	1.12	0.93
5	Ca Lung (Non-Small Cell)	3000	1.22	0.84	1.10	0.91

6	Ca Prostate	3000	1.20	0.77	1.13	0.90
7	Ca breast	5000	1.20	0.76	1.07	0.97
8	Multiple Myeloma	5000	1.19	0.74	1.15	0.96
9	Plasmacytoma	5400	1.20	0.76	1.16	0.89
10	Ca Ovary	3000	1.20	0.73	1.14	0.92

Table 2. Shows mean and maximum dose to critical structures calculated for IMRT and Rapid arc plan

S. N.	Primary Site of Carcinoma	Dose Prescription	IMRT							Rapid Arc						
			Whole Brain	Brain Stem		Optic Nerve	Optic Chiasm	Int. Ear (L)	Int. Ear (Rt)	Whole Brain	Brain Stem		Optic Nerve	Optic Chiasm	Int. Ear(Lt.)	Int. Ear(Rt.)
			<Dmean	<Dmax	1 cc.	<Dmax	<Dmax	<Dmax	<Dmax	<Dmean	<Dmax	1 cc.555	<Dmax	<Dmax	<Dmax	<Dmax
1	Ca Breast	5000	4115	5100	5210	5086	4900	4890	4875	3000	4880	4925	4429	4123	3958	3980
2	Ca Breast	5000	4220	5050	5198	5074	4850	4884	4876	2885	4828	4970	4398	4168	3816	3895
3	Ca Breast	5000	4312	5078	5167	5035	4892	4820	4876	2880	4825	4913	4367	4133	3781	3822
4	Small Cell Ca Lung	2800	2280	2830	2912	2846	2750	2750	2740	1895	2685	2785	2377	2176	2082	2154
5	Ca Lung (Non-Small Cell)	3000	2313	3079	3129	3034	2975	2880	2842	1860	2889	2995	2319	2089	2156	2216
6	Ca Prostate	3000	2356	3087	3115	3016	2988	2845	2866	1825	2830	2935	2392	2028	2212	2295
7	Ca breast	5000	4150	5120	5216	5097	4920	4910	4860	3000	4891	4920	4495	4100	3900	3950
8	Multiple Myloma	5000	4273	5036	5197	5056	4966	4860	4887	2933	4758	4845	4423	4080	4425	4476
9	Plasmacytoma	5400	4328	5487	5587	5432	5340	5245	5260	3032	5210	5291	4852	4256	4850	4913
10	Ca Ovary	3000	2256	3087	3134	3009	2979	2877	2838	2212	2813	2876	2013	2095	2368	2289

IV. Conclusion

From the above results it was concluded that with IMRT technique PTV was not getting radiation dose uniformly distribution, however in Rapid Arc plan more than 95% dose coverage was uniformly achieved in PTV ring. One can easily visualize the comparison in both plans IMRT and Rapid Arc in figure-7. Outline boundary of 95% dose colourwash follows the shape finely same as PTV-ring. Isodose distribution comparison between IMRT and Rapid arc plan reveals that the Rapid Arc plan provides more uniform dose coverage as compared to IMRT plan and also provides less spillage to the whole brain area. Dose Homogeneity and Dose Conformity Index was close to unity for Rapid Arc plans as compared to IMRT plans. The maximum dose to critical structures was less for Rapid Arc plans than IMRT plans. So, it was concluded the Rapid Arc treatment (VMAT) shows better dose coverage and less dose to critical organ as compared to IMRT plan and Rapid Arc technique of radiation delivery is most suitable technique for ring type structure like skull bone metastases irradiation.

Acknowledgement

We would like to thanks Dr Tripti Nagariya, Dean Pt. J.N.M.Medical College, Raipur and Dr. Vishnu Dutt, Director Medical Education, Chhattisgarh for their continuous encouragement and support for the study. We are also thankful to all the staff of Department of Radiotherapy for their cooperation.

References

[1] Hata M, Koike I, Omura M, Maegawa J, Ogino I, Inoue T, Noninvasive and curative radiation therapy for sebaceous carcinoma of the eyelid. Int J Radiat Oncol Biol Phys, 2012; 82:605–611.

[2] Able CM, Mills MD, McNeese MD, Hogstrom KR, Evaluation of a total scalp electron irradiation technique. Int J Radiat Oncol Biol Phys, 1991; 21: 1063–1072.

[3] Mellenberg DE, Schoeppel SL, Total scalp treatment of mycosis fungoides: the 4 x 4 technique. Int J Radiat Oncol Biol Phys, 1993; 27: 953–958.

[4] Akazawa C, Treatment of the scalp using photon and electron beams. Med Dosim, 1989; 14:129–131.

[5] Wojcicka JB, Lasher DE, McAfee SS, FortierGA, Dosimetric comparison of three different treatment techniques in extensive scalp lesion irradiation. Radiother Oncol, 2009; 91: 255–260.

[6] Kelly PJ, Mannarino E, Lewis JH, Baldini EH, HackerFL, Total dural irradiation: RapidArc versus static-field IMRT: a case study. Med Dosim 2012; 37:175–181.

[7] Lozano F, Perez N, Iglesias A, Xu X, Amendola MA, Scott M, Companioni E, Beatriz E Amendola, Volumetric arc therapy for total scalp irradiation: case report for a recurrent basal cell carcinoma of the scalp, ecancer, 2017; 11: 737.

[8] Ostheimer C, Hubsch P, Janich M, Gerlach R, Vordermark D, Dosimetric comparison of intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) in total scalp irradiation: a single institutional experience. Radiat Oncol J., 2016; 34: 313–21.

[9] Hu J, Xiao W, He Z, Kang D, Chen A, Qi Z, Target splitting non-coplanar RapidArc radiation therapy for a diffuse sebaceous carcinoma of the scalp: a novel delivery technique. Radiat Oncol., 2014; 9: 204.

[10] Song JH, Jung JY, Park HW, Lee GW, Chae SM, KayCS, et al. Dosimetric comparison of three different treatment modalities for total scalp irradiation: the conventional lateral photon-electron technique, helical tomotherapy and volumetric-modulated arc therapy. J Radiat Res. 2015; 56: 717–26.

[11] Inui S, Ueda Y, Ohira S, Tsuru H, Isono M, Miyazaki M, Koizumi M, Teshima T,Novel strategy with the automatic noncoplanar volumetric-modulated arc therapy for angiosarcoma of the scalp, Inui et al. Radiation Oncology, 2020; 15:175.

G.S. Gautam, et. al. “Brain Saving Radiotherapy in Skull Metastases using Volumetric Modulated Arc Technique: A Dosimetric Analysis.” *IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)*, 21(04), 2022, pp. 26-34.