

Dosimetric comparison of non-coplanar three-dimensional conformal radiation therapy (nc3DCRT) planning and radio biologically optimized partial arc volumetric modulated arc therapy (VMAT) planning of unilateral brain tumours – A retrospective study

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Abstract

Aim: To compare non-coplanar 3DCRT planning and partial arc VMAT planning dosimetrically for unilateral brain tumours.

Introduction: Intensity modulated radiation therapy has gained wide popularity as a radiotherapy treatment of choice for many clinical sites. Volumetric modulated arc therapy is a kind of therapy in which rather than using multiple static fields at different gantry angles, one or multiple full or partial arcs are used for radiotherapy planning and treatment. Its ability to provide superior target coverage and better normal tissue sparing makes it a treatment of choice over conventional and 3DCRT radiotherapy planning techniques. But, on the same time volume of low dose region which can increase probability of secondary malignancy in VMAT planning is reported to be on the higher side. Our study compares various parameters of plan quality along with low dose volumes in the techniques under comparison.

Materials and methods: 10 anonymized patients with unilateral malignant brain tumours previously treated with nc3DCRT were selected for the study and planned with partial arc VMAT. Conformity Index, Homogeneity Index, Target Coverage, Doses to critical structures and normal brain were compared.

Conclusion: In our study by using VMAT technique we were able to reduce doses to critical structures (Brainstem, optic nerves, and optic chiasm) significantly, got better target coverage along with lesser number of MUs per fraction and significant reduction in low dose volume and reduction in doses to contralateral normal structures including lesser amount of low dose volume.

Keywords: Partial arc volumetric modulated arc therapy, low dose volume, dose conformity, radiobiological optimization, Monte Carlo calculations.

1. Introduction

Volumetric modulated arc therapy (VMAT) is now becoming a standard of radiotherapy treatment for head and neck cancer, Ca prostate and many other clinical sites [1,2]. In VMAT treatments planning single or multiple full or partial arcs are used instead of static multiple beams at different gantry angles and modulation of intensity is achieved by variation of MLC leaf speed, gantry rotation

speed and dose rate during the rotation of the gantry [3]. Advantage of VMAT over static beam Intensity Modulated Radiation Therapy (IMRT) is lesser number of monitor units (MUs) and reduced treatment time [4]. VMAT and IMRT provide better target conformity and critical structures sparing compared to 3DCRT treatment planning but on the same time low dose volume in normal tissue is significantly more in VMAT and IMRT [5,6].

This increased low dose volume is a matter of concern as it increases risk of radiation induced carcinogenesis particularly in the patients for which a long survival is expected [7]. In our Institute non coplanar 3DCRT (two lateral wedged field along with one vertex field) is standard radiotherapy technique of care for brain tumours along with IMRT, partial arc and complete arc VMAT for complex cases in which critical structures are close to or overlapping with target volume and extent of disease.

The purpose of this study is to evaluate low dose volumes (V2 Gy, V5 Gy and V10 Gy) and other dosimetric plan quality parameters such as Conformity Index (CI), Heterogeneity Index (HI), Target Mean Dose, doses to critical structures inVMAT and compare it to non coplanar 3DCRT in complex unilateral brain tumours those treated with high dose of radiation and with close proximity or overlapping with critical structure.

2. Materials and Methods

For this study 10 anonymized patients of brain tumours (Anaplastic Astrocytoma, GBM, etc.) with mean age 39.7± 11.7 years, previously treated with non coplanar 3DCRT were selected. These patients were earlier simulated in Philips Brilliance Big Bore CT with 3 mm slice thickness for radiotherapy planning. GTV was contoured on CT with the help of MRI and adequate CTVs and PTVs margins were given to the targets as per our Institute protocol and critical structures brainstem, eyes, optic nerve, and optic chiasm, temporal lobes, cochlea were

delineated in Monaco Treatment Planning System (version V5.11.03). These patients were planned by using differentially weighted two lateral parallel opposed wedged fields and one Superior Vertex field and calculated with collapsed cone algorithm, the weight of the lateral beam from the opposite side of the PTV was kept minimum possible to reduce high doses to contralateral structures and normal brain without compromising target coverage and treated in Versa HD linear accelerator with image guidance.

For our study, all these patients were again planned with partial arc VMAT in Monaco TPS with radiobiological based optimization with 6 MV (FF) partial arc, as partial arc provides better contra lateral organ sparing [8]. Target objectives were defined as Equivalent Uniform Dose (EUD) and for critical structures with serial and parallel radiobiological constraints, physical constraints such as quadratic overdose, conformity and maximum dose were also used to control maximum dose inside the target and to reduce dose sharply outside the target volumes in IMRT constraint tab.[9,10].

For all plans minimum segment width was taken as 10 mm, maximum number of control points were restricted to 150 and 3 numbers of subarcs were used for each plan. Grid spacing was kept as 3 mm and statistical uncertainty of 1 % per calculation was used for Monte Carlo (XVMC) dose calculations of the plans.

Target objectives and dose constraints for all the plans are listed in table 1.

Table1: lists target objectives and constraints for critical structures for 3DCRT and VMAT plans

Target/ Critical Structure	Target Objective or Dose Volume Constraint
HRPTV	Dose (60 Gy), Minimum 95 % of PTV should be covered with 95 % of Prescribed Dose V107< 10 % , V115< 1 %
LRPTV	Target Dose (50 Gy), Minimum 95 % of PTV should be covered with 95 % of Prescribed Dose
Brain Stem, Optic Nerves and Optic Chiasm	Maximum dose should be less than 54 Gy, 1cc < 60 Gy
Contra lateralTemporal lobe	Max dose < 60 Gy
Eyes	Max dose < 45 Gy
Spinal Cord	Max dose < 44 Gy
Cochleae	Mean Dose < 45 Gy

For plan comparison, Paddick Conformity Index, which is a measure of dose conformality to the target and prescription dose spilling outside the target volume was used and can calculated using the equation

$$CI = (TV \text{ covered by PIV})^2 / TV \times PIV$$

Where PIV= Prescription Isodose volume and TV= Target Volume,

And Homogeneity Index, which is a measure of dose homogeneity inside the target was calculated with the equation

$$HI = (D_{max} - D_{min}) / \text{Mean Dose}$$

Perfect values of CI and HI are 1 [11,12].

Low dose volumes in Remaining Volume at Risk (RVR)V2 Gy, V5 Gy and V10 Gy were evaluated and

compared. Number of monitor units for both the plans were also compared.

3. Results

In Monaco TPS, it takes a little less than 1 hour to generate a clinically acceptable quality VMAT plan for most of the brain tumours; almost same amount time is required to generate a clinically acceptable quality 3DCRT plan in two phases.

Table 2 compares various plan quality parameters for HRPTV and LRPTV for both the plan techniques. Statistical analysis of the data was done with paired sample t test.

Table 2: Plans parameters for PTVs and Number of Mus.

Plan Parameters	Non Coplanar 3DCRT	Partial Arc VMAT	p Value
Conformity Index (CI) for HRPTV	0.56 ± 0.16	0.84 ± 0.06	0.0001
Homogeneity Index (HI) for HRPTV	1.08 ± 0.03	1.09 ± 0.02	0.51
V95% for HRCTV	98.24 ± 1.12	99.01 ± 0.95	0.17
V 100% for HRPTV	63.86 ± 6.62	93.10 ± 3.77	0.0001
V 107% for HRPTV	0.92 ± 1.71	7.82 ± 5.15	0.003
V 100% for LRPTV	98.83 ± 1.80	98.50 ± 1.72	0.68
Number of MUs	548.46 ± 62.05	445.39 ± 60.46	0.001

Mean volume of HRPTV is 209.5 ± 98.22 cc and for LRPTV 288 ± 80.8 cc. It is evident from the comparison that partial arc VMAT plan is superior to nc3DCRT in terms of dose conformality with a statistical significance of p << 0.05 but it is more heterogeneous compared to nc3DCRT plan (statistically insignificant p > 0.05). 95 % of

dose to the HRPTV is almost comparable but 100% dose coverage is better in VMAT plan with a statistical significance p < 0.05. Number of MUs per fraction is lesser in VMAT plan than nc3DCRT plan which is statistically very significant (p=0.001). V100 % coverage to the LRPTV is also comparable in both the techniques.

Table 3: lists the comparison of doses to critical structures in both the plan techniques.

Critical Structure	Max Dose (Gy) in Non Coplanar 3DCRT	Max Dose (Gy) in Partial Arc VMAT	p Value
Brainstem	47.97 ± 12.44	42.64 ± 19.40	0.17
Optic Chiasm	51.01 ± 10.41	45.00 ± 15.02	0.03
Contralateral Eye	14.53 ± 11.41	14.10 ± 8.00	0.23
Ipsilateral Eye	38.95 ± 6.77	40.22 ± 6.77	0.73
Contralateral Optic Nerve	34.45 ± 15.95	24.41 ± 12.57	0.04
Ipsilateral Optic Nerve	44.66 ± 13.17	35.79 ± 17.40	0.02
Contralateral Temporal Lobe	43.21 ± 7.41	35.77 ± 8.25	0.01

VMAT planning technique is able to reduce the doses to most of the critical structures better than 3DCRT planning. In ipsilateral eye maximum doses are lesser in 3DCRT planning because of partial shielding of LRPTV in lateral or vertex field otherwise there is significant reduction in other critical structure doses in VMAT plans but still doses to eyes are below the prescribed constraint and difference is statistically non significant. There is

significant (p = 0.01) dose reduction to contralateral temporal lobe and contralateral optic nerve in VMAT plan.

V2 Gy, V5 Gy and V10 Gy (Volume receiving 2 Gy, 5 Gy and 10 Gy of radiation dose) for RVR (RVR is unspecified tissue and it is created by subtracting PTVs Volumes and critical structures volumes from total patient volume) is tabulated in table 4.

Remaining Volume at Risk (RVR)	3DCRT	VMAT	P Value
V2 Gy	62.47 ± 10.42	46.32 ± 8.41	0.0015
V5 Gy	45.45 ± 6.5	38.83 ± 7.06	0.0019
V10 Gy	37.99 ± 6.38	33.03 ± 7.05	0.02

In IMRT and VMAT planning there is increased amount of low dose and ultra low dose volume compared to conventional and 3DCRT planning. Efforts are done to restrict this low dose region as much as possible. In our study we are not only able to reduce low dose and ultra low dose volume V10, V5 and V2 significantly, but also total number of MUs per fraction which also reduces leakage and scatter doses to the patient.

VMAT planning provides superior results in every aspect of treatment planning except that VMAT plans are comparably heterogeneous (statistically insignificant p > 0.05).

4. Discussion

In our study we have demonstrated that by using partial arc VMAT, we can achieve better critical structures sparing along with superior target coverage and also can reduce doses to contralateral structures compared to nc3DCRT. Miura H, Fujiwara M, Tanooka M, et al [3] has shown similar results for partial arc VMAT plan for maxillary cancer where they were able to reduce doses to contralateral normal structures compared to full arc VMAT. Jiang X, Li T, Liu Y, et al has also shown similar results in contralateral lung sparing using the partial arc compared to full arc with comparable PTV coverage [13]. In our study, with partial arc VMAT dose reduction to contralateral temporal lobe is shown in figure 1.

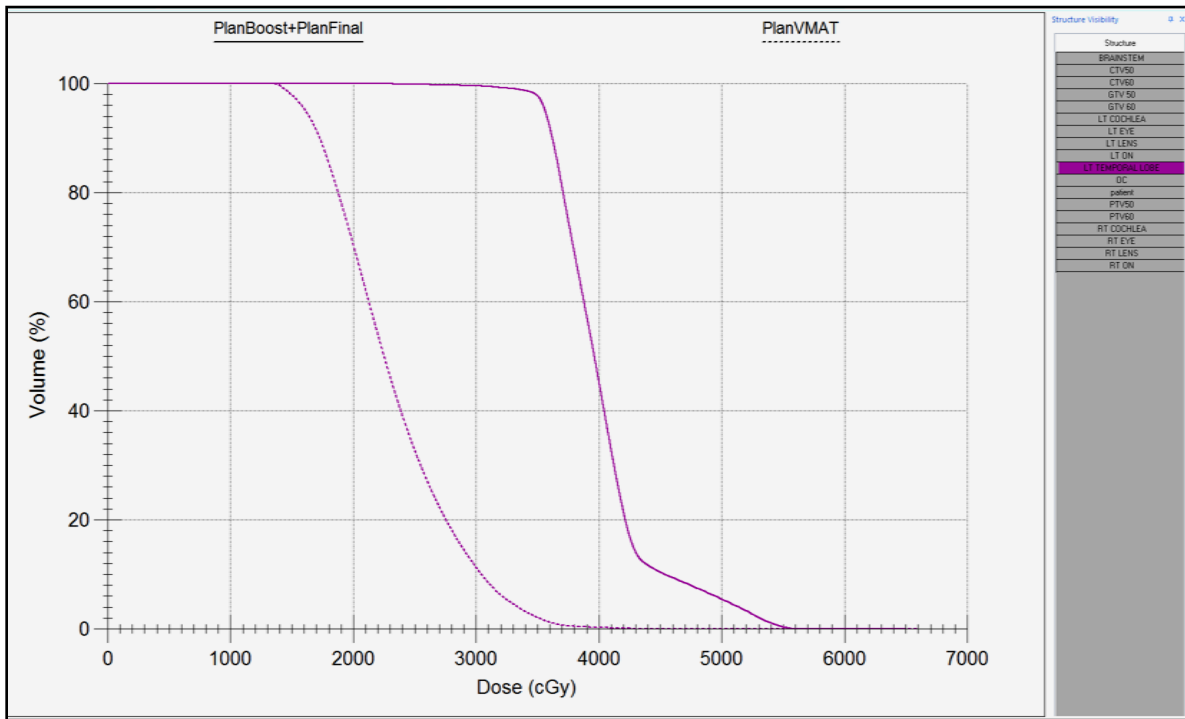


Figure 1: Shows sparing of contralateral temporal lobe in ncVMAT (dotted line) plan compared to 3DCRT plan.

Lucy Ward, ACT, CMD in his presentation “Malignant Glioma: Is VMAT truly better than 3DCRT?” has shown results similar to our study in terms of superior target coverage and normal tissues sparing with VMAT planning over 3DCRT. Figure 2 Shows Dose Volume Histogram (DVH) comparisons between two techniques [14].

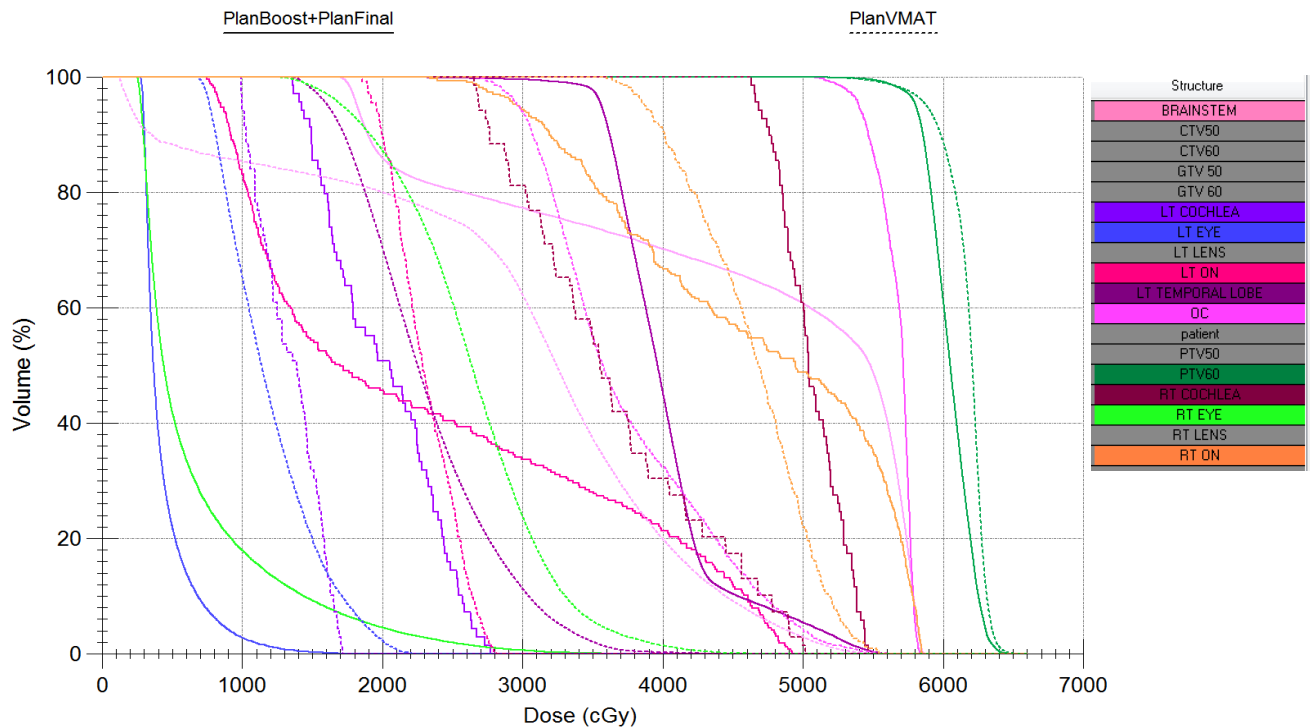


Figure 2: Shows improved target coverage and better critical structures sparing (dotted lines) in VMAT plan

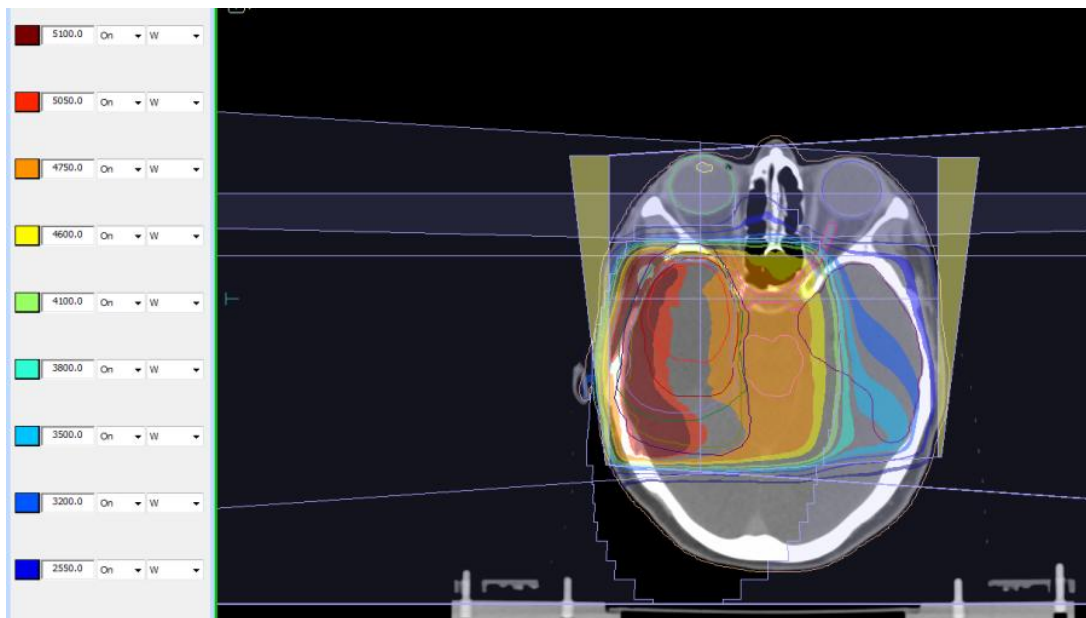


Figure 3a: nc3DCRT plan



Figure 3b: partial arc VMAT plan

Figure 3 Shows isobands of different doses in 3DCRT and ncVMAT plan. More spread of doses in nc3DCRT plan is evident.

We can achieve high quality plans using partial arc VMAT planning of unilateral brain tumours and this technique can successfully reduces amount of low dose volume in normal brain, thereby decreases probability of radiation induced second malignancies. Same technique can also be used for low grade brain tumors where long survival is expected.

5. Conclusion

VMAT planning is expected to provide superior target conformity along with better normal tissue sparing compared to 3DCRT plan but on the same time it is more complex having more number of MUs per fraction and increased amount of low dose volume.

But, in our study by using VMAT technique we could reduce doses to critical structures (Brainstem, optic nerves, and optic chiasm) significantly along with better target coverage with lesser number of MUs per fraction and significant reduction in low dose volume and reduction in doses to contralateral normal structures.

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