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Dosimetric Comparison of Three - Dimensional Conformal Radiation Therapy (3DCRT) and Posterior Partial Arc Volumetric Modulated Arc Therapy (VMAT) Plan for Craniospinal Irradiation

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ABSTRACT

Introduction: This study compares three dimensional conformal radiotherapy (3DCRT) and Posterior Partial Arc volumetric modulated arc therapy (VMAT) planning techniques for treating craniospinal irradiation.
Material and Methods: Ten patients with Medulloblastoma were retrospectively considered for the study and replanned using 3DCRT and posterior partial arc VMAT techniques using MONACO 5.11, treatment-planning system (TPS). The dose prescribed for the planning target volume (PTV) was 36Gy in 20 Fractions, followed by a boost dose to the brain volume. The parameters such as Tumour coverage, the organ at risk (OAR) doses, conformity index (CI), homogeneity index (HI), and total monitor units (MU) were calculated for both plans. Comparison of the two planning techniques done using paired sample t-test.
Results: PTV coverage in VMAT and 3DRT was 97.994±2.2533 and 94.041±2.24907, respectively. The mean CI in 3DCRT and VMAT was 1.3459±0.3279 and 1.1714±0.1238, respectively, and the mean HI in 3DCRT and VMAT was 1.1151±0.0247 and 1.0634±0.0198, respectively. OAR doses were comparable in 3DCRT and VMAT. The total MU in 3DCRT and VMAT were 198.12±8.9539 and 978.403±170.0104, respectively.
Conclusion: Posterior Partial Arc VMAT plans are superior to 3DCRT in target coverage, conformity index, and homogeneity index. The OAR doses in the two planning techniques were comparable whereas, the duration of treatment was higher in VMAT compared to the 3DCRT method. Additionally, low dose volumes are reduced in VMAT due to partial posterior arcs. Considering all the factors, it can be concluded from the study that Posterior Partial Arc VMAT plans are superior to 3DCRT.

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Introduction

Medulloblastoma is considered one of the most common types of paediatric tumors, with an occurrence rate of 15% to 20% and 20% to 40% among all CNS tumors in children and infants, respectively [1,2]. Such tumors are found rarely in adults, and account for less than 1% of all brain tumors [3]. The median age of occurrence in children is 5-6 years, and in adults, it is 25years, and the ratio is 2:1 for males to females [4]. These tumors can be managed post-surgery by craniospinal irradiation (CSI) combined with chemotherapy or hormonal therapy, which offers overall survival of 5 years in 65% of the patients [5].

For the treatment of medulloblastoma and germ cell tumors, CSI is one of the essential radiotherapy methods. At the same time, CSI is a quite challenging radiotherapy technique that involves careful treatment planning, treatment delivery, and verification of radiation dose to obtain accurate results [6]. Also, craniospinal irradiation is one of the complex treatment procedures which involves uniform irradiation of the brain and spinal axis by avoiding overdosage and under dosage at the field junctions as multiple radiation beams are involved in the treatment [1].

Various treatment techniques have been developed for the CSI, including 3DCRT, Intensity Modulated Radiation Therapy(IMRT), VMAT, tomotherapy, etc., which offers various advantages and disadvantages [1,5]. For the high-risk medulloblastoma, currently, a radiation dose of 36Gy in 20fractions with 1.8Gy per fraction will be delivered, and the posterior fossa will

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be given a boost dose of 18Gy as standard care of radiotherapy practice [4].

In conventional radiotherapy, CSI can be treated with two lateral opposed fields for the craniocervical region and one or two anterior-posterior adjacent beams for spine region based on the length of the spine [7]. Planning radiotherapy for CSI is the most complicated part of conventional radiotherapy, which include various difficulties such as setting the treatment beam by taking care of beam divergence, shifting the isocentre after a certain number of fractions by 0.5 to 1 cm, known as feathering to prevent over-dosage and under-dosage of the tumor if the patient setup is not accurate, and also matching the beams by rotation of couch or collimator to the desired angle [8].

CSI can be delivered in a prone position which offers an advantage over supine positioning as field junctions between the skull and spine can be directly visualized [9]. But due to uncomfortable patient positioning, especially for elderly and debilitated patients and also, young children, who may require general anaesthesia while delivering radiotherapy, many hospitals have adopted supine positioning for treatment [9,10]. Supine positioning also offers several advantages, such as patient comfortability, stability, reproducibility of treatment, and enhanced ability to deliver anaesthesia [9].

As the overall five-year survival rate in the patients having an average risk of Medulloblastoma when they are treated with chemotherapy in combination with radiotherapy is 80%, these patients have a high risk of longs term side effects when they are treated with conventional radiotherapy where the target volume is closer to the organs that are radiosensitive. In such patients, reducing the dose of the OARs is a crucial concern [11]. There are various other techniques developed such as IMRT, VMAT, proton therapy, tomotherapy, etc. which are advantageous in avoiding the junction hot and cold spot regions and decrease radiation dose to the non tumor volume [7].

VMAT with a single arc or combination of arcs can be used with multiple isocentres to treat CSI. Many types of research have shown the conformal and homogenous dose distribution to the tumor by avoiding OARs with a minimum achievable dose [3,12,13]. VMAT, since it contains fluence patterns that are overlapped between brain and spine fields, it provides an additional advantage over 3DCRT as it does not include shifting of isocentres for the feathering purpose to match the field junctions [14].

This study is conducted to compare 3DCRT and partial posterior arc VMAT techniques for CSI planned with MONACO 5.11 TPS, with respect to the conformity, homogeneity, tumor coverage, and OAR dose.

Materials and Methods

The study included ten patients with age between 2-47(median 9) years having Medulloblastoma and treated between 2018-2021 at Kasturba Medical College, Manipal, were retrospectively considered for the study and replanned using 3DCRT and posterior partial arc VMAT techniques with MONACO 5.11(Elekta, 2016) TPS.

The patients were immobilized using a thermoplastic mould (ORFIT) for the brain and spine axis. Computed Tomography (CT) scans (Philips Brilliance Big Bore CT) with 3mm a slice thickness was acquired and these scanned images were exported to MONACO TPS. The target volumes such as Clinical Target Volume (CTV) and Planning Target Volume (PTV) for the brain and spine, were delineated separately by the Physicians. The OARs such as brain, eyes, lens, optic nerves, optic chiasma, cochlea, lungs, heart, liver, kidneys, bowel, stomach, and other organs in the body were delineated using the standard guidelines provided by Radiation Therapy Oncology Group (RTOG).

Dose prescribed to PTV was 36Gy in 20 fractions, followed by the boost dose of 19.8Gy in 11 fractions to the tumor volume, which translates into 1.8Gy per fraction. VMAT and 3D-CRT plans for all the 10cases were generated by MONACO 5.11 TPS, which uses the Monte Carlo algorithm for VMAT and collapsed cone algorithm for 3DCRT. Collapsed cone algorithm accounts for volume and lateral energy transport.

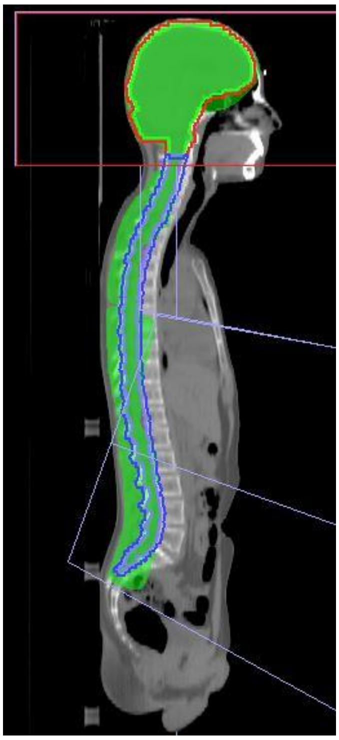

Figure 1. CSI with 3DCRT: Beam arrangement

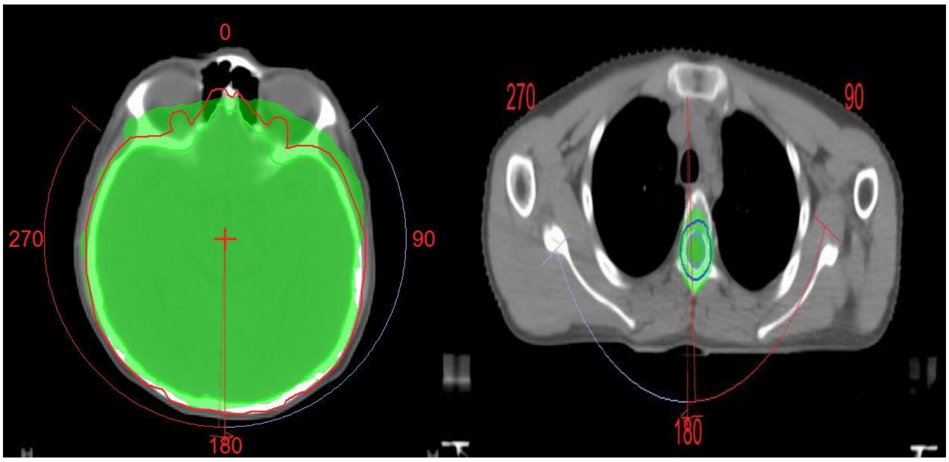

Figure 2. CSI with VMAT: Beam arrangement Brain (Left), Spine axis (Right)

Treatment planning

3DCRT plan with half beam technique was performed for all patients. Two lateral opposed beams with 6MV photon energy were selected for the brain PTV. Since all the patients involved were positioned supine on the treatment couch for spine PTV, a posterior beam was used to cover the entire spine. The energy selection for the PA field was based on the depth of the tumor from the skin surface. For paediatric patients, a dual isocentric plan with one posterior field adjoined by lateral opposed brain fields was sufficient to cover the entire tumor volume, including the brain and spine. A treatment plan with three isocentres with two posterior fields for the spine was used for adult patients. The second PA beam was placed by rotating the couch by 90^o so that the two PA beams were well-matched with each other and the hot and cold spots were avoided (Figure1).

Treatment plan with VMAT techniques were generated with partial posterior arcs for brain and spine axis. For the brain PTV, first arc with gantry starting angle from 50^o to 80^0 stopping at 180^o and the second arc with starting angle at 180^o stopping at 300^o to 330^o were used. For the spine axis first arc with a gantry starting angle from 100^o to 130^o stopping at 180^o and the second arc starting with a gantry angle 180^o stopping at 220^o to 250^o were used (Figure2). The beam angles were decided to avoid the entrance dose to the uninvolved OARs present throughout the PTV. VMAT was planned with 6MV photon energy for brain PTV, and for spine, 6MV or 10MV photon energy was selected. In the case of children, two partial arcs with a single isocenter were sufficient to cover the entire spine along with brain fields, but for adults since the length of the spine was larger, partial arcs with two isocentres for spine field along with brain fields were used. Plan optimization was done to get the best plan with PTV coverage of 95% or more by achieving all the OARs within the Prescribed limit.

Treatment Plan evaluation

The quantitative evaluation and analysis of the VMAT plans and 3DCRT plans were performed utilizing standard Dose Volume Histogram (DVH) analysis. Using the plan review option available in the Monaco 5.11 TPS, the VMAT and 3DCRT plans were compared using dose statistics. The mean and maximum doses to the OAR involved and the target dose in terms of the volume received by 95%, 100%, and 107%, and dose received by 2%, 5%, 95%, and 98% of the prescribed tumor dose were calculated. CI and HI were calculated using the formula mentioned below, and also the number of MU were noted down using the TPS for both plans.

HI is a parameter used to quantify the homogeneity of the radiation dose across the tumor volume and it can select the best-optimized plan out of the available plans by comparing their dose distributions. Ideally, HI should be 1. Closer the HI value to 1 better will be the homogeneity of dose distribution. The equation for Homogeneity Index is given by;

$$\text{HI} = \frac{\boldsymbol{D_{5\%}}}{\boldsymbol{D_{95\%}}}$$

D5% and D95% refers to the doses received by 5% and 95% of target volumes respectively [15].

CI is a plan evaluation index proposed by Radiation Therapy Oncology Group (RTOG), which can compare different plans based on target coverage. The conformity Index helps to find the degree of congruence existing between the prescribed dose and PTV.

$$\text{CI}=\frac{\boldsymbol{V_{RI}}}{\boldsymbol{PTV}}$$

V_{RI} is the volume received by the reference isodos [16]. Unity is an ideal value for this index, and deviation implies the absence of conformity. The statistical analysis was done using paired t-test.

Results

Dosimetric comparison between 3DCRT and VMAT was made in various aspects. The mean tumor coverage, including brain and spine, was 94.041with standard deviation (SD) ±2.4907 and 97.694 with SD ±2.2533(p-value 0.000769) for 3DCRT and VMAT, respectively. This shows that, there is a significant difference in the tumor coverage between 3DCRT and VMAT. VMAT plans showed superiority in tumor coverage, where 95% of the tumor volume is receiving more than 95% of the dose (Figure3). The hotspots (V107%) were comparable as the P-value is 0.08429, but it is slightly more in 3DCRT plans. The total MU for the VMAT plans was higher (p-value 0.000000171), leading to more duration of treatment execution (Table1).

HI in VMAT plans is found to be superior (p-value 0.000327) compared to 3DCRT resulting in better dose homogeneity across the entire brain and spine volume. However, CI was almost similar in both planning techniques (p-value 0.064978) (Figure4, 5). OAR doses were comparable in 3DCRT and VMAT. There is not much improvement in the VMAT plans in terms of OAR doses (Figure6).

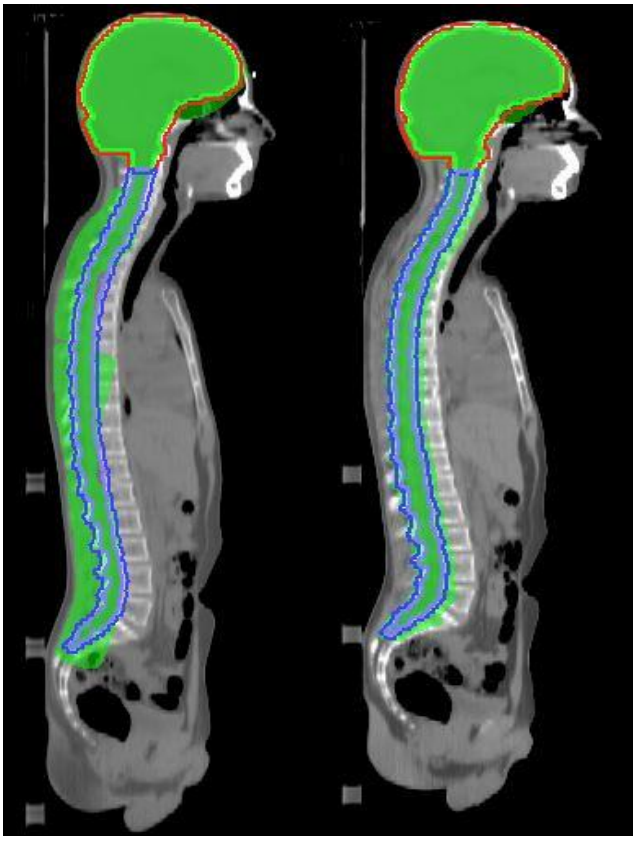

Figure 3. Dose Coverage (95% of prescribed dose): CSI with 3DCRT (Left) & VMAT (Right)

Table 1. Summary of comparison data between 3DCRT and VMAT

	3D-CRT	VMAT	P-Value
Dose received by 2% volume D2%(Gy)	35.5673±5.4265	34.7671±5.2255	0.016071
Dose received by 95% volume D95%(Gy)	31.6143±5.2292	32.5245±4.9996	0.002811
Dose received by 98% volume D98%(Gy)	29.7472±6.1786	31.6381±4.9775	0.01539
Volume receiving 95% dose V95%(%)	94.041±2.4907	97.694±2.2533	0.000769
Volume receiving 107% dose V107%(%)	1.079±1.5702	0.046±0.0937	0.08429
Homogeneity Index(H.I)	1.1151±0.0247	1.0634±0.0198	0.000327
Conformity Index(C.I)	1.3459±0.3279	1.1714±0.1238	0.064978
MU	198.12±8.9539	978.403±170.0104	0.000000171

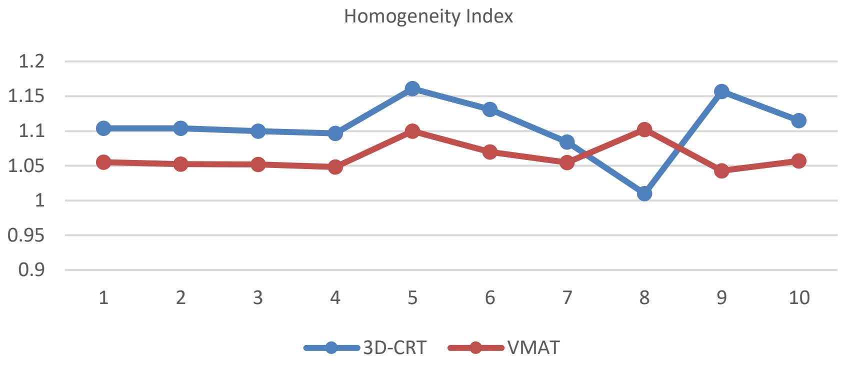

Figure 4. Comparison of homogeneity index for all ten patients

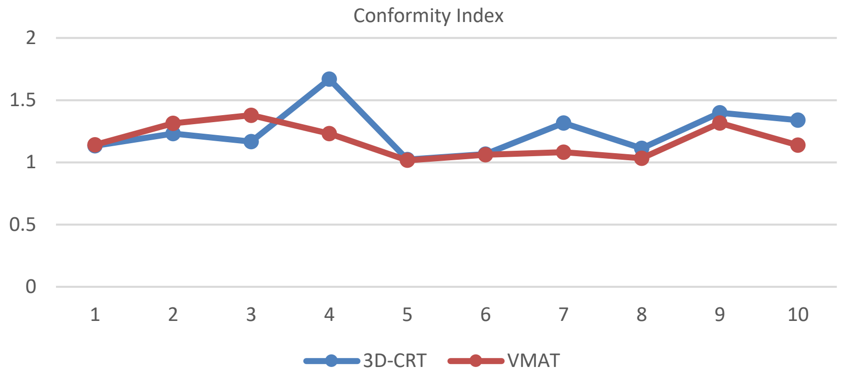

Figure 5. Comparison of conformity index for all ten patients

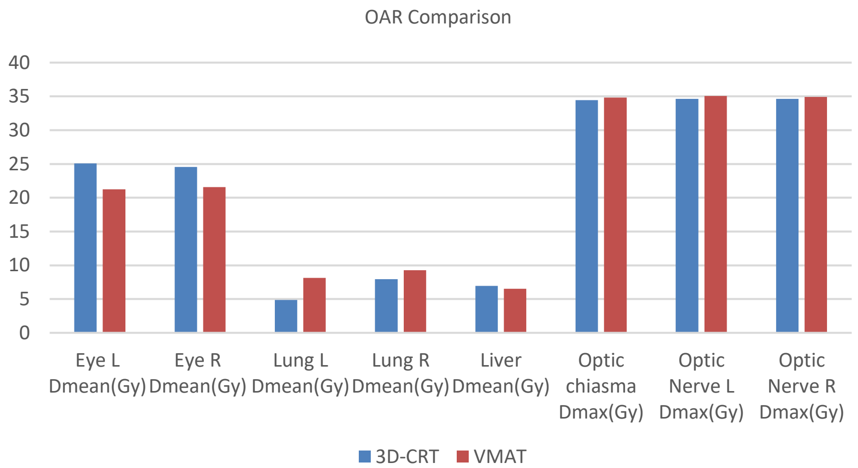

Figure 6. Comparison of OAR doses in 3DCRT and VMAT

Discussion

Medulloblastoma is one of the common types of paediatric tumors, and post-surgery, the management of this disease with radiation therapy is an important factor [1]. Two types of treatment techniques have been used for the CSI in the current study. Target coverage in the case of VMAT was more than 95% in the entire brain and spine region and reducing hot spot areas to be within 107% was possible without compromising the tumor coverage (Figure3). The volume receiving 107% of the dose was relatively more prominent in 3D-CRT, with hot and cold spot regions visibly present, which was not observed in VMAT. However, the hotspots were comparable in both techniques, as the P-value is 0.08429. In the case of paediatric CSI, it was made sure that hot spot regions were further reduced by 105%. At the same time, the overall dose coverage in 3DCRT was up to 94%. Most of the tumor under dose occurred at the junction region between the adjacent radiation beams. In most cases, it was unavoidable.

Additionally, the hot areas were also found in the junction region. Segments (Field within a field) were created to reduce the hotspot areas. The significant difficulty faced in 3DCRT was to plan CSI for adult and obese patients where the depth of the spine from the skin surface was more than 2 to 3cm. In such cases, although photon beam energy of 15MV was used, covering entire spine volume with 95% dose with avoidance of hot areas was challenging.

The two treatment techniques were compared in terms of OAR doses. Since posteriors partial arcs were used in VMAT, the resulting OAR doses were comparable in 3DCRT and VMAT. There was not much improvement in the VMAT plans with respect to OAR doses except for OARs in head region. Whereas, especially in the brain volume, as partial arcs were used, the organs such as eyes, lens, optic nerve, and cochlea doses were relatively reduced, which is unavoidable in 3DCRT. This would be beneficial during the irradiation of boost volume. If the boost volume is close to the OARs such as eyes, lens, optic nerves, brainstem, and optic chiasma, then achieving the OAR doses to be within the expected limit in the sum plan(phase1+boost) would be challenging in 3DCRT. The results in terms of OAR are comparable to a study conducted by Gerhard Pollul et al., on the contrary, there is a slight improvement in the conformity and homogeneity indices in both the techniques in the current study[17]. A comparison of 3DCRT, IMRT, and VMAT was made by Mathew T et al., They found mean dose to the OARs were high in VMAT compared to the other two techniques. The current study has resulted in similar OAR doses in both the planning techniques except for some OARs, especially in brain volume. This is because of the reduction in the angular sweep of VMAT arcs [18].

The HI and CI values in VMAT were higher than 3DCRT. However, 3DCRT plans also showed comparatively good results as well. These results were similar to the results obtained by Jianzhou Chen et al., wherein it was identified that the dose homogeneity and conformity to the entire tumor volume was superior in VMAT with minimal radiation dose to the OARs[19]. Yangqing Sun et al., compared IMRT, VMAT, and Helical tomotherapy (HT). The results suggested that HT gives great HI, CI with lesser OAR dose when compared to the other two techniques. So advanced technologies are providing better results than 3DCRT[20]. The time required to deliver the VMAT plan was higher than 3DCRT as the calculated MUs for the VMAT plans were higher (p-value 0.000000171) excluding treatment setup and verification time. In adult patients, if the spine's length is more than 50cm to 55cm, treatment plan with three isocentres including brain volume are required, which contributes to the additional setup time where the patient must lie down on the treatment time a longer duration.

Various other techniques give better results than 3DCRT in most aspects. As 3DCRT is one of the complicated procedures, different advanced technologies can be used to provide better treatment delivery [20-24]. DS Sharma et al. proposed in the study where 3DCRT and IMRT (with tomotherapy and Linac) plans were compared that in case of non-availability of IMRT_tomo better plan can be obtained with IMRT [22].

As the partial arcs were used for the brain as well as the spine axis, the dose to the organs was comparatively minimized, especially in the case of eyes, lenses, optic nerves, and other organs, and also the low dose volumes were reduced with the help of partial arcs which would have been on the higher side with 360º arc gantry rotations. Due to the benefit of partial posterior arcs, the average dose to the surrounding normal structures and OARs has successfully been reduced along with the reduction of radiation-related toxicities due to the areas receiving low radiation doses.

For all the ten patients VMAT and 3DCRT plans were generated to achieve 95% tumor coverage with negligible hotspot. In all the plans, the dose to the OARs were within the required dose limit (Based on Quantitative Analyses of Normal Tissue Effects in Clinic). The results suggested that posterior partial arc VMAT plans were better for CSI than 3D-CRT with respect to tumor coverage and OAR dose. CI and HI in both the techniques were comparable but VMAT showed more homogenous and conformal dose distribution than 3DCRT. As the delineation of some of the OARs were missing, overall comparison of those organs has not been made in the current study.

Conclusion

CSI is a complex and rigorous treatment planning process where treatment delivery and verification are also the most complicated. But having newer and more advanced technologies in the planning process, these complications can certainly be reduced. VMAT planning technique with partial arc for the brain and spine axis seems ideal for CSI. Minimizing the OAR doses with increased conformity and homogeneity in the entire PTV volume is possible. The hot and cold regions can be satisfactorily removed with the VMAT, which is unavoidable in 3DCRT. In addition, the field junctions between the brain and spine axis that would likely produce overdose and underdose to the PTV in 3DCRT also be successfully avoided in VMAT with better PTV coverage to the entire brain and spine axis. Considering all the factors, the current study can conclude that VMAT plans are better than 3DCRT. In the case of the availability of VMAT, planning CSI with VMAT could be a better choice, especially for adult patients. The abstract of this study has been presented in the Association of Medical Physicists of India Conference (AMPICON), North Chapter, held at Jodhpur.

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