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Original Research Article

Comparison of Dosimetric Parameters between Two Treatment Planning Methods of IMRT in Brain Tumour Patients

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Abstract

Introduction: Intensity-Modulated Radiotherapy (IMRT) is becoming the standard of practice since it delivers precision radiotherapy to the planning target volumes (PTV) and minimizes dose to Organs-At-Risk (OARs). Two planning methodologies exist i.e. Preselected Beam Optimization (PSBO) or Beam Angle Optimization (BAO) which are selected by the physicist and the treatment planning system respectively. Both methods aim to achieve prescription to planning target volume (PTV) with maximal sparing of organs at risk (OARs). The present study aims to compare the dosimetric parameters between the Beam angle optimization (BAO) with preselected beam angle orientation (PSBO) in brain tumour patients.

Materials and Methods: Present study was conducted in the department of Radiation Oncology. Twenty patients of brain tumour planned by PSBO were randomly selected. A new plan was created for each patient with BAO method. Dosimetric parameters of PTV (V95%, Dmax, Dmean, D2, D50, D98, HI, CI, and MUs) and OAR (brainstem, eyes, lenses, optic nerves, cochleae, hippocampi, and normal brain tissue) were compared.

Results: The dosimetric parameters of PTV in PSBO and BAO plans are almost similar and none of the parameters have shown a statistically significant difference.

There was a difference of >1Gy in various OARs like brainstem Dmax, optic nerves Dmax, lenses Dmax, Dmin Dmax of right hippocampus and left hippocampus Dmin, though it was not statistically significant. Rest of the OARs like, both eyes, cochleae and normal brain had a difference of <1Gy and not statistically significant.

Conclusion: Dosimetric parameters of PSBO patient planning method are equivalent to BAO method. PSBO may be more useful since it is an individualized planning and may further utilise less time with growing experience of the medical physicist.

Keywords: IMRT, PSBO, BAO, Brain Tumours.

Introduction

Radiation therapy is an important modality in treatment of brain tumours after surgery. With the advancements of newer radiotherapy techniques, Intensity Modulated Radiotherapy (IMRT) is becoming the standard of practice since it delivers precision radiotherapy to the planning target volumes (PTV) and minimizes dose to Organs-At-Risk (OARs). IMRT helps reduce the volume of normal brain tissue irradiated at higher doses which may result in potential decrease in long-term toxicity of radiotherapy.

IMRT may be planned by Pre-Selected Beam Orientation (PSBO) or by Beam-Angle Optimization (BAO). In the planning methodology of PSBO, the medical physicist pre-defines the beam angles as per their experience, while in the planning methodology of BAO, the treatment planning system optimizes the beam angles to achieve the prescribed dose prescription and dose-constraints.

PSBO methodology may require more time in comparison to BAO methodology, though the individualized planning for each patient may be better achieved. The present study aims to compare the dosimetric parameters between these two common methods and tries to evaluate any advantage in any methodology.

Materials and Methods

Study Setting: Department of Radiation Oncology, Shri Ram Murti Institute of Medical Sciences

Study Design: Observational study

Study population: For the present study 20 patients of Brain Tumours which were planned by IMRT with PSBO were randomly selected.

Target volume delineation and Organs at Risk:

Target volume delineation was done on Contrast MRI of brain. Contrast-enhanced CT scan (1.5mm thickness) was also taken and fused with the MRI images. The target volume delineation included PTV (which includes the residual tumour if any, microscopic spread, along with setup errors of positioning of patient) and OARs (like brainstem, optic chiasma, bilateral eyes, bilateral lenses, bilateral cochleae, bilateral hippocampi, and normal brain tissue) which have to be spared by radiotherapy as much as possible. Delineation was done as per the RTOG guidelines [1].

Radiotherapy planning and prescription

1. The planning and contouring were done using Varian Eclipse version 13.6 Treatment Planning System (TPS), and calculation was done using Anisotropic Analytical Algorithm (AAA).
2. In the Preselected beam orientation, the beam angles are chosen by a medical physicist. The selection of beams depends upon the OARs adjacent to PTV, after which the optimisation was done giving upper and lower objectives to PTV, upper objectives to serial organs and mean objectives to parallel organs.
3. The dose prescription to PTV in Low Grade Gliomas was 54 Gy in 30 fractions and in High grade Giomas was 59.4 Gy in 33 fractions.
4. The dose constraints to OARs were Brainstem: D_{max} <54Gy, Chiasma: D_{max} <55 Gy, Right /Left Optic Nerve: D_{max} <55 Gy, Right/ left Lens: D_{max} <7Gy, Right/ Left Eye: D_{max} <50Gy, Right/ Left Cochlea: D_{mean} <45Gy.

For the present study, the treatment plans using PSBO which had already been executed had to be compared with the new plans using BAO. For this, another new plan was generated by BAO, using the same Target Volume delineation, prescription and Radiotherapy planning objectives.

Dosimetric parameters to be compared in both planning methods:

PTV dosimetric parameters:

1. V95, Dmax, Dmean, D2, D50, D98, pConformity index (pCI), Homogeneity index (HI)
2. Homogeneity index (HI) -

$$HI = \frac{(D_{2\%} - D_{98\%})}{D_{50\%}},$$

where $D_{2\%}$, $D_{50\%}$, $D_{98\%}$ are the absolute dose delivered to 2%, 50% and 98% of PTV, HI of zero indicated a homogenous distribution.

Conformity Index (CI) – Conformity Index is a measure of degree of conformity of the absorbed dose distribution to the PTV. For the evaluation of CI, Paddick's[2] conformity Index was used.

$$pCI = \frac{(TV^2_{PIV})}{(TV \times PIV)}$$

Where TV_{PIV}, TV and PIV are the prescribed isodose volume over the target volume, Target Volume, Target Volume and Prescription isodose volume respectively.

OAR dosimetric parameters:

The dosimetric parameters evaluated were Brainstem: D_{max}, Chiasma: D_{max}, Right/Left Optic Nerve: D_{max}, Right/ Left Lens: D_{max}, Right/Left Eye: D_{max}, Right/ Left Cochlea: D_{mean}, Right/ Left Hippocampus: D_{min}, D_{max}, D_{mean}, Normal Brain Dose: D_{min}, D_{mean}.

The doses to PTV and OARs were analysed from Cumulative Dose–volume histograms (DVHs), as recommended in ICRU Report 83, 2010[3].

Statistics

Statistical significance was calculated using unpaired 't' test. A p-value of <0.05 was considered as statistically significant

Results

The PTV Dosimetric parameters and OARs were compared between PSBO and BAO generated plans, the results of which have been shown in Table-1 and Table-2

Table 1: Dosimetric parameters of the PTV in two techniques (Mean ± SD)

Parameters	Preselected Beam Orientation (Mean± SD)	Beam Angle Optimisation (Mean± SD)	P – value
V95%	96.38±4.84	96.15±4.40	0.87
Dmax	61.3805±3.00	61.40±3.05	0.50
Dmean	58.0455±2.45	57.17±3.94	0.40
D2	59.448±2.64	59.523±2.71	0.92
D50	58.266±2.50	58.19±2.58	0.93
D98	55.247±2.83	55.8655±2.74	0.48
Homogeneity index	0.082±0.082	0.084±0.08	0.93
Conformity index	0.87±0.03	0.86±0.03	0.90
MUs	1163.15±694.72	1196.9±678.53	0.87

Table 2: Dosimetric parameters of the OARs in two techniques (Mean ± SD)

Parameters		Preselected Beam Orientation (Mean ± SD)	Beam Angle Optimisation (Mean ± SD)	p– value
Brainstem	Dmax	47.64±10.94	45.95±15.24	0.68
Optic Chiasma	Dmax	41.50±17.96	41.35±17.96	0.97
Right Optic Nerve	Dmax	30.98±19.53	29.75±18.58	0.83

Left Optic Nerve	Dmax	27.18±18.22	29.45±17.59	0.69
Right Lens	Dmax	5.32±1.81	4.80±1.93	0.38
Left Lens	Dmax	5.11±1.75	4.94±2.01	0.78
Right Eye	Dmax	22.34±11.59	21.78±12.53	0.88
Left Eye	Dmax	21.87±13.65	22.77±13.79	0.83
Right Cochlea	Dmean	22.85±17.06	23.56±17.36	0.64
Left Cochlea	Dmean	19.35±15.28	20.48±16.24	0.82
Right Hippocampus	Dmin	27.13±19.15	29.78±17.30	0.64
	Dmax	46.12±17.91	44.74±18.85	0.81
	Dmean	35.87±20.46	36.72±19.95	0.89
Left Hippocampus	Dmin	21.58±16.27	25.60±17.82	0.47
	Dmax	38.97±16.72	40.29±17.82	0.81
	Dmean	33.52±19.50	32.017±18.12	0.80
Normal Brain	Dmin	1.62±1.26	1.63±1.24	0.98
	Dmean	21.34±6.43	22.34±6.47	0.62

The dosimetric parameters of PTV in PSBO and BAO plans are almost similar and none of the parameters have shown a statistically significant difference.

There was a difference of >1Gy in various OARs like brainstem's Dmax, optic nerves' Dmax, lenses' Dmax, right hippocampus' Dmin, Dmax and left hippocampus' Dmin, though it was not statistically significant. Rest of the OARs like, both eyes, cochleae and normal brain had a difference of <1Gy and not statistically significant.

Discussion

Selection and optimization of beam angles in IMRT are crucial to meet the goal of radiotherapy. Manual beam placement in PSBO needs several trial-and-errors to achieve an adequate treatment plan, which may be good, but time consuming and perhaps also may not be optimal. On the other hand, optimal plans can be generated using AI-based computational software by BAO where beam angles are optimized by treatment planning systems.

In a study by Ventura *et al* [4], the BAO advantages in head and neck cancer patients was highlighted among 40 patients of nasopharyngeal cancer; 3 patients were selected for specific analysis where BAO plans were compared with equidistant beam angle solutions. In their results, for all cases, BAO generated plans had higher target coverage and better sparing of normal tissues. The equidistant beam angle of this study is similar to our PSBO planning method where equidistant beams ranging from 5-9 were preselected. The results of our study in brain tumours are in contrast to that of Ventura *et al* [4]. There is no statistical significance in PTV and OAR parameters between the two methodologies. The probable reason may be in individualized planning in each brain tumour and more time spent to achieve the optimal plan. Further, in the study of Ventura *et al* [4], noncoplanar beams were used which may have led to better dosimetric parameters in BAO.

Shukla *et al* [5] in a study of 30 patients treated with IMRT for carcinoma prostate, carcinomas of head and neck and carcinoma esophagus, made two IMRT plans. The PSBO arrangement had 7-9 fields while the second plan using BAO was made with algorithms compatible with treatment planning system. The DVHs generated showed that the PTV parameters like CI, HI, QI, were almost same for the two plans. The OARs received almost identical or slightly better doses in case of BAO as compared to BSO, but was

statistically not significant. In our present study, the findings are similar to Shukla *et al* and PTV parameters, CI, and HI do not show any significant difference. The Monitor units were lesser in BAO plans compared to PSBO in the study by Shukla *et al* [5].

The difference in MUs were 6.59% in head and neck cancers and 6.93% in esophageal cancers. In contrast to this our study reveals lesser MUs in PSBO plans (1163 vs 1197) with a difference of 2.8% which was found to be not statistically significant. The reduction in MUs is always of clinical advantage which has been emphasized in the study compared.

Wang *et al* [6] studied the effectiveness of noncoplanar IMRT planning using a parallelized multiresolution beam angle optimization (PMBAO) in paranasal sinus carcinoma patients. The PMBAO treatment plans were compared with PSBO plans using 9 equally spaced coplanar beams the dose homogeneity was better using PMBAO 5 beam configuration but the dose conformity did not improve which is similar to our findings.

There was a statistically significant decrease in the doses of both eyes and optic nerves. Brianstem and optic chiasma also had reduced doses in PMBAO but were not statistically significant. In our present study, brainstem Dmax was lower in BAO as seen in the study by Wang *et al*. that was not statistically significant. The Dmean of normal brain was little higher in BAO in contrast to the study by Wang *et al* (22.34 vs 21.34) which was not statistically significant. Better dosimetric parameters in PMBAO can be attributed to the noncoplanar beam configurations used which was not done in our study.

Llacer *et al* [7] has discussed about the practical methodology of noncoplanar beam orientation selection in cranial IMRT. It suggests that Automatic Beam Selection (ABS) can be a useful tool in reducing the number of beam selections. He mentions the pros and cons of ABS and Manual selection of beams by medical physicists. The drawback of ABS methodology is that some organs may be outlined and declared OARs which may not be needed to be considered in manual beam selection depending on a particular case. The medical physicist may know the priority that a particular organ may not receive any significant dose if he or she selects the beam orientations so as to avoid it.

On the contrary, the ABS doesn't know the priority of selected OARs. The study also puts forward the point that the ABS results may be a guide to the clinical physicist or may be a starting point of his experience for planning the patient which may allow them modifications in future plans. Considering these facts and the results of our present study where there is no statistical significance between dosimetry of PTV and various OARs, the PSBO plans may give more invidualized clinically relevant plans but time may be the barrier due to the increased patient load.

Liu *et al* [8] studied the beam angle optimization and reduction for IMRT of non-small lung cancers. They showed concern that commonly used nine equal-spaced beams increases treatment time and patient discomfort when respiration controlled techniques like gating and breath-holding are used during treatment. They suggested that the number of beams should be minimized to improve the efficiency of treatment delivery. By their study, the concluded that the use of fewer beams (5-7) in lung cancers could result in acceptable plan quality along with improved treatment efficiency.

In our study on brain tumours, the issue of organ motion as in case of lung cancers is not relevant. Though we have similar results in both treatment methodologies (PSBO, BAO) in brain tumours, the point of increased treatment time and patient discomfort seems valid and important in cases where organ motion is involved. We would like to study the two planning

methodologies in cases of lung cancer and see whether we can achieve similar results in terms of plan quality, use of lesser beams and lesser time.

In a study by Leung *et al* [9], dosimetric comparison of different beam arrangements was seen in head and neck cancers treated by IMRT. The five-beam arrangement method in this study was equally spaced beams (ESB), co planar BAO, non co planar BAO, 2-Arc VMAT, 3-Arc VMAT. The different head and neck cancer sites included cancers of nasopharynx, oral cavity, larynx, maxillary sinus and parotids. In cases of cancer nasopharynx, the target conformity and homogeneity was better in ESB for high and intermediate risk PTV which was attributed to the less irregular shape of target volumes.

The low-risk PTV which extended to both sides of the neck was irregular in shape and therefore no co planar BAO and VMAT plans demonstrated relatively better dose coverage. They concluded by suggesting no co planar BOA and 3-arc VMAT has better plans than 5-beam arrangements. Further, 3-arc VMAT may be directly better than noncoplanar BAO in terms of shorter treatment delivery time. These findings are in contrast to the study done by our institution by Anjana *et al*.[10].

In our previous institutional study, PSBO methodology was a better method than BAO in cases of nasopharyngeal carcinomas. Anjana *et al* [10] suggested on the basis of two major findings in this study; firstly, out of 20 patients being planned, for 3 patients, beam angles chosen by BAO were invalid and could not be executed on the treatment machine which leads to the inference that BAO method does not take in account the limitations of the machine.

Secondly, the total monitor units planned by PSBO method was lower and statistically significant in comparison to BAO method (1128.7 vs 1237.8, p=0.045). In the present study on brain tumours' planning in 20 patients, 2 plans generated by BAO algorithms were non-executable. Initially, these plans were non co planar when limitations were not applied on couch and gantry angles. On re-planning by co planar beam arrangements, executable plans could be achieved. This limitation of BAO methodology needs validation in further studies.

Srivastav *et al* [11] compared dosmetric parameters in Manual Beam-Angle Selection (MBS) and BAO for IMRT plans in 15 carcinoma head and neck and carcinoma prostate patients. Their results showed superior sparing of OARs and lesser Monitor Units (13.1% lesser in head and neck cancer, p=0.012; 14.7% in prostate, p=1.003E-5) in BAO IMRT plans and thus concluded that BAO provides an advantage over MBS. Our present study shows no difference between PSBO and BAO plans in sparing of OARs. In contrast to Srivastav *et al* [11], there is 2.8% decrease in Monitor Units in PSBO plans compared to BAO though it was not statistically significant.

Our results can be supported by the view of Llacer *et al* [7]. who suggested that with increasing experience in planning, the new methodology may achieve equivalent or better plans in terms of plan quality, lesser beams, lesser treatment time and executability.

Recently, Carrasqueira *et al* [12]. suggested an automated bi-level optimization approach for IMRT plans. He discusses that the IMRT treatment planning can be divided into two parts- first, finding the optimal selection of beam directions, second, finding the optimal fluence intensities for corresponding beams. The optimal beam directions can improve the quality of IMRT plans and minimize radiation to the OARs. The fluence intensity could be optimized or modulated to fulfil the dosimetric prescription. A similar concept has been discussed by Bangert *et al* [13] a decade before, where he suggests incorporation of fluence

optimization (FO) into beam angle selection (BAS) by combinatorial optimization (CO).

The study was done in 272 treatment plans where five different BAS strategies were used using co planar and non co planar beams. The authors concluded that BAS strategies incorporating FO by CO provide lesser dose to OARs in both coplanar and spatially non co planar beam arrangements.

This bi-level optimization approach seems optimistic and should be explored in different sites. This may have a freedom to select lesser beams which may be an advantage for sites where organ motion is an issue and thus may be treated in lesser time with more comfort to the patient.

Conclusion

Dosimetric parameters of PSBO patient planning method are equivalent to BAO method. With growing experience in planning, PSBO may be more useful and utilise less time of the medical physicist.

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