RESEARCH ARTICLE

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Dosimetric Importance of Implementing Jaw Tracking Technique in Radiotherapy Treatment Plan Execution

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Abstract

Objective: To study the dosimetric importance of Jaw tracking technique in reducing the doses to organs at risk (OAR) while achieving the optimal dose coverage for the target. **Methods:** We retrospectively selected ten Glioblastoma cases and for each patient, two plans were created namely Static Jaw Technique Dynamic Intensity Modulated Radiotherapy plan and Jaw Tracking Technique D-IMRT plan with 6 MV for Varian Truebeam™ STx machine using Eclipse Treatment planning system. Both plans were analyzed and compared based on various dosimetric parameters for Planning Target Volume (PTV) and OARs. The dose agreement between the Portal dose image prediction and the portal dosimetry measurement was also analysed using gamma analysis criteria of 3%/3mm, 2%/2mm and 1%/1mm of dose distance/distance-to-agreement. **Results:** The dosimetric parameters evaluated for both plans showed that most of the parameters gave significant P values, where D50% of PTV showed a mean difference (Δ) of 0.45 with significant P value, 0.0104. Similarly mean dose, D2%, D98%, D80% to PTV, Conformity Index and Conformation number showed Δ values of 0.45, 0.51, 0.41, 0.40, 0.02 and 0.01 with their significant P values as 0.0138, 0.0172, 0.0313, 0.0466, 0.0279, 0.0561 respectively. The Δ values and significant P values obtained among OARs are 0.54;0.0224 for brainstem, 0.54;0.0017 for RT optic nerve, 0.52;0.0001 for LT optic nerve, 0.59;0.0040 for optic chiasm and for the healthy tissues it showed the values with their mean dose, V5 and V30 parameters as 0.19;0.0115, 0.59;0.0067 and 0.25;0.0125 respectively. The JTT plans showed better passing results of gamma analysis criteria when compared to SJT plans. **Conclusion:** The findings in the studies emphasize the importance of using JTT technique in the radiotherapy treatment plans as it lowers the risk of acute or late toxicity and secondary radiogenic cancers in patients by reducing the OAR doses and achieves better tumor control.

Keywords: IMRT plans- SJT technique- JTT technique- MLC- DD/DTA

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Introduction

The main challenge of radiotherapy practice is to spare the critical organs from radiation exposure without compromising the target coverage. This purpose is achieved by the advanced techniques of dynamic intensity modulated radiotherapy (D-IMRT) compared to conventional radiotherapy and three dimensional conformal radiotherapy (Xu et al., 2017; Yang et al., 2017). The IMRT plans still deliver some lower doses to the Organs at Risk (OARs) nearby the tumor volume due to the interleaf leakage of multi leaf collimators (Chow et al., 2005; Pasquino et al., 2006). This is because, in IMRT technique while the lower and upper jaws stay static during irradiation, the multi leaf collimators move continuously at variable speeds. The combination of upper jaws and the Multi Leaf Collimator (MLC) which are mounted as tertiary collimators allows transmission of less than 0.1% of the radiation intensity (Cadman et al., 2005). As the beam energy increases, the MLC transmission increases and as stated in some studies, the transmitted dose rate could be higher for different jaw sizes covered only by MLC than that shielded by jaws or both jaws and MLC (Mohan et al., 2008; Varian, 2001). To overcome this discrepancy and to lower the interleaf and intraleaf leakage of radiation to the patient, movement of collimator along with the MLCs as close as possible to its aperture during treatment was developed. This jaw tracking technique was developed in the latest model of Varian Linear accelerator namely TrueBeam™ (Varian Medical Systems, Palo Alto, CA) as well as its corresponding Treatment Planning System (TPS), Eclipse V.10.0, and its newer versions where the dose calculation algorithm takes into account of the contribution of collimator scattering in dose delivery during the jaw movement at each control point for the same planning system (Varian, 2010). In this Jaw Tracking Technique (JTT) developed in TrueBeam™, the jaws trace the MLC apertures during treatment delivery and thereby reduces the dose to the OARs lying close to the

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target which potentially enhances the dose fall-off towards the treatment field edges and surrounding OARs which is explained in many studies that showed the dosimetric advantage of jaw tracking technique in Head and Neck (H&N) and prostate cancer patients (Schmidhalter et al., 2007; Kim et al., 2014).

Many studies were carried out on the dosimetric importance of jaw tracking technique and one among them evaluated the dosimetric importance of jaw tracking technique in step and shoot IMRT but couldn't reveal a clinically significant dose reduction in the treatment delivery and also failed to indicate the patient criteria which would mainly benefit from jaw tracking (Joy, 2012). Another study compared prostate as well as head and neck cancer cases by using jaw tracking and sliding window IMRT technique where a larger impact on head and neck cases due to small field aperture increase in the 'X' direction was observed (Schmidhalter et al., 2007). As the OARs constraints are more stringent in radiosurgery when compared to conventional cases and while considering the concavity of target volume and large monitor units (MUs) per fraction, jaw tracking is very much beneficial for radiosurgery. In a study, it was stated that Spine radiosurgery is an ideal case for using jaw tracking technique as per the shape of target and location of the cord (Snyder et al., 2015).

The main focus of this study is to show the dosimetric importance of Jaw tracking technique in lowering the doses to OARs while achieving the optimal target dose coverage. Moreover, this study is carried out in glioblastoma cases which is prone to fewer setup errors due to patient movement upon using the appropriate immobilization device and also this is the site that possesses more number of OARs. Thereby the study highlights the advantage of giving the exact results and benefits of using JTT with the least interference of any other factors which may contribute to the dose of OARs. In addition, this study assessed the portal dosimetry results of plans with and without using the Jaw tracking technique and also the difference in their MUs and treatment time.

Materials and Methods

Patient Selection

A total of ten patients were selected for this study which is retrospective radiotherapy cases of glioblastoma and the patients were in the age group of 45 to 85 years after getting approval from the institutional ethical committee.

Treatment Planning and Plan Evaluation

The patients were immobilized using custom-made thermoplastic masks and headrests and were simulated in a headfirst supine position for which 3mm thickness Computed Tomography (CT) images were acquired. The range of body for CT acquisition was defined to make sure to have enough CT anatomy beyond the PTV borders (≥5cm), for calculation of peripheral dose using Anisotropic Analytical Algorithm (AAA), version 15.06. The acquired images were later transferred to the TPS (Eclipse TPS version 15.06). The MRI images taken in a similar position were imported to the TPS for registration with the CT images acquired for better localization and delineation of tumor volumes and OARs based on the treatment protocol. Initially, the Gross Tumor Volume (GTV) was delineated on CT images involving all positive lymph nodes with reference to the registered images. Following the GTV, the Clinical Tumor Volume (CTV) was contoured based on the primary tumor size and its involved nodes and other microscopic spread. This CTV was then expanded by 5mm in all directions to delineate the Planning Target Volume (PTV) as per International Commission on Radiation Units and Measurements (ICRU) 50 and 62. Later on, the critical organs or OARs were contoured such as brainstem, optic chiasm, right eye, left eye, right lacrimal, left lacrimal, left optic nerve, right optic nerve and healthy tissue.

For each patient, two plans were created namely Static Jaw Technique (SJT) D-IMRT plan and Jaw Tracking Technique (JTT) D-IMRT plan with a total of twenty plans with the same dose prescription 60Gy in 30 fractions. The SJT plans were created for 6MV photon beam energy with Eclipse™ TPS using 7 fixed beam gantry angles and sliding window dynamic delivery. All plans were optimized using the Photon optimizer (15.6.05) algorithm to achieve the given planning objectives and then calculated the volumetric doses using the AAA algorithm with 2.5mm grid size for a Truebeam linear accelerator equipped with 120 leaves HD Multi Leaf Collimator (MLC) with 2.5mm and 5mm leaf widths. The reference volume selected for treatment plans was PTV. For all the plans, the dose distributions met the plan objectives which was that at least 95% of the PTV should cover 95% of the dose prescribed and the dose maximum should not exceed a value of 107% while the dose to the adjacent normal tissues was minimized as lesser as possible from their stipulated tolerance values. To create the JTT D-IMRT plans, the SJT D-IMRT plans were copied and the volumetric dose reset was done to clear the pre-calculated dose in the plan. Later the jaw tracking function was selected during leaf motion calculation (LMC) and volumetric dose. In the JTT plan, all the machine and optimization parameters were kept similar to that of the SJT D-IMRT plan including the Normal Tissue Objective (NTO) parameters and ring structures. The MLC and jaw margin from PTV is 5mm and 10 mm respectively and for SJT plans, the X and Y jaws are not changed by LMC whereas in JTT plans, the X and Y jaws are set separately at each control points. The different dose values followed for OARs are shown in Table 1.

Both the SJT and JTT plans were analyzed and compared based on the Dose Volume Histogram (DVH), tumor coverage and OAR doses. Various other dosimetric plan parameters such as Homogeneity Index (HI), Conformation Number (CN) and Dose Gradient index (DGI) were also used for evaluating both the plans (Akpati et al., 2008). The homogeneity index is calculated as

$$\text{Homogeneity Index (HI)} = (D_{2\%} - D_{98\%}) / D_{50\%}$$

where $D_{2\%}$, $D_{98\%}$ and $D_{50\%}$ are dose received by 2 %, 98 % and 50 % volumes respectively and the ideal values of HI is 0. The CN was calculated and noted for both plans to evaluate the conformity of dose to target by the following formula

$$CN_{95\%} = (TV_{pi} / TV) \times [TV_{pi}/V_{pi}]$$

where TV_{pi} is Target Volume within the 95% prescribed isodose volume, TV is the tumour volume and Vpi is the Volume of 95% of prescribed isodose volume where the CN ideal value is 1. The DGI parameter was calculated and noted down using the formula PI/D50% whose ideal value is 1, where PI is the prescribed isodose volume and D50% is the volume of 50% of prescribed isodose volume. The Conformity Index (CI) is defined as PI/TV and the coverage index (COVI) defined as TV_{pi}/TV were calculated and noted down whose ideal value is 1. Unified Dosimetry Index (UDI) is another dosimetric parameter whose ideal value is 1 and is calculated using the formula

UDI = UDI [CI]×UDI[CF]×UDI[HI]×UDI[DG]

where the CI-coverage index, CF-conformity index, HI-Homogeneity Index and DG-gradient index. This is a tool used to compare and evaluate any treatment plan regarding dose coverage, conformity, homogeneity, and dose gradient. The mathematical logic-based UDI formula is:

$$UDI = \left(\prod_{k=1}^{4} W_k \left[\left|1.0 - DI_k\right| + 0.1\right]\right) \times 10^4 \quad (1)$$

Where DI_k is dosimetry index, each of the four indices and W_k is the weighting factors as per the relative importance of all the four components.

For the OARs, the maximum dose, the mean dose and appropriate values of volume receiving xGy were noted. The calculated plan difference of the patients was analysed statistically using one sample 't-test and considered significant if the P-value was less than 0.05. An additional healthy tissue was also defined which is the patient CT volume excluding the PTV volume whose V5, V30 and mean dose were noted down, where V5 is the volume receiving 5 Gy and V30 is the volume receiving 30 Gy dose.

Technical characteristics of plans

The total Monitor units (MUs) and Treatment Time (TT) were also assessed and compared for each plan of all patients.

Plan verification and dose distribution measurement

For both SJT and JTT plans, the dose distribution verification was done with portal dose image prediction (PDIP) (Varian Medical Systems, Pala Alto, USA). The portal dosimetry measurement was done with a portal imaging device which is priorly calibrated for darkfield, flood field and dose normalization for usage as per the recommendation of the manufacturer (Varian, 2003). Dose agreement between the PDIP and the portal dosimetry measurement was analyzed for both SJT and JTT plans of all patients by using gamma index criteria of 3%/3mm of DD/DTA, which was further evaluated with 2% 2mm and 1%1mm criteria for comparison.

Results

The dosimetric parameters evaluated for JJT and STT plans are tabulated below. Table 1 shows the plan PTV parameters evaluated for both plans and it is very evident that most of the parameters under study has significant P values where D50% showed a P value of 0.0104 with a difference (Δ) of 0.45 and similarly other parameters like mean dose, D2%, D98%, D80% to PTV, CI95% and CN showed significant P values of 0.0138, 0.0172, 0.0313, 0.0466, 0.0279, 0.0561 and Δ values of 0.45,0.51,0.41, 0.40,0.02, 0.01 respectively. Table 2 gives the dosimetric parameter values of different OARs noted down in both

Table 1. Dose Constraints Values Used in Treatment Planning

Organs at Risks	Dose Constraints
Brainstem	D_{max} < 54 Gy
Optic chiasm	D_{max} < 45 Gy
Eyes	D_{max} < 45Gy
	D_{mean} < 35Gy
Lacrimal gland	D_{max} < 20 Gy
Optic nerves	D_{max} < 54 Gy

D_{max}, Maximum dose; D_{mean}, Mean dose

Table 2. PTV Parameters for Static Jaw and Jaw Tracking Plans

PTV Parameters	Jaw Tracking Technique (JTT)	Static Jaw Technique (SJT)	Δ	P-value
Mean Dose(Gy)	61.13±1.3	61.58±0.98	0.45	0.0138
D2%(Gy)	63.23±1.06	63.74±0.73	0.51	0.0172
D98%(Gy)	57.09±1.99	57.50±1.64	0.41	0.0313
D50%(Gy)	61.33±1.22	61.78±0.95	0.45	0.0104
D80%(Gy)	60.36±1.42	60.76±1.14	0.4	0.0466
CI95%	1.07±0.05	1.09±0.06	0.02	0.0279
HI95%	0.10±0.02	0.11±0.02	0.01	0.2741
CN95%	0.88±0.03	0.87±0.03	0.01	0.0561
COVI	0.98±0.01	0.97±.01	0.01	0.5038
DGI	0.45±0.03	0.44±0.05	0.01	0.7651

Δ, Difference between static jaw technique (SJT) and jaw tracking technique (JTT) plan.

Table 3. OARs Parameters for Static Jaw and Jaw Tracking Plans

OAR	Parameters	Jaw Tracking Technique (JTT)	Static Jaw Technique (SJT)	Δ	P-Value
Brainstem	Max Dose (Gy)	46.48±14.1	47.02±14.1	0.54	0.0224
Rt Eye	Mean Dose (Gy)	6.90±2.9	8.03±4.8	1.13	0.1333
Lt Eye	Mean Dose	7.22±4.2	8.22±5.3	1	0.11
Rt Optic nerve	D1% (Gy)	19.13±12.7	19.67±3.1	0.54	0.0017
Lt Optic nerve	D1% (Gy)	21.57±15.2	22.09±15.4	0.52	0.0001
Rt Lacrimal	Mean Dose (Gy)	14.92±7.5	15.54±8.4	0.62	0.2851
Lt Lacrimal	Mean Dose (Gy)	12.44±9.7	12.83±10.4	0.39	0.339
Optic Chiasm	D1% (Gy)	32.39±12.5	32.98±12.5	0.59	0.004
	Mean Dose (Gy)	7.35±3.2	7.54±3.3	0.19	0.0115
Healthy Tissue	V5 (%)	28.51±12.8	29.10±13.1	0.59	0.0067
	V30 (%)	9.06±4.3	9.31±4.5	0.25	0.0125

Δ, Difference between static jaw technique (SJT) and jaw tracking technique (JTT) plan.

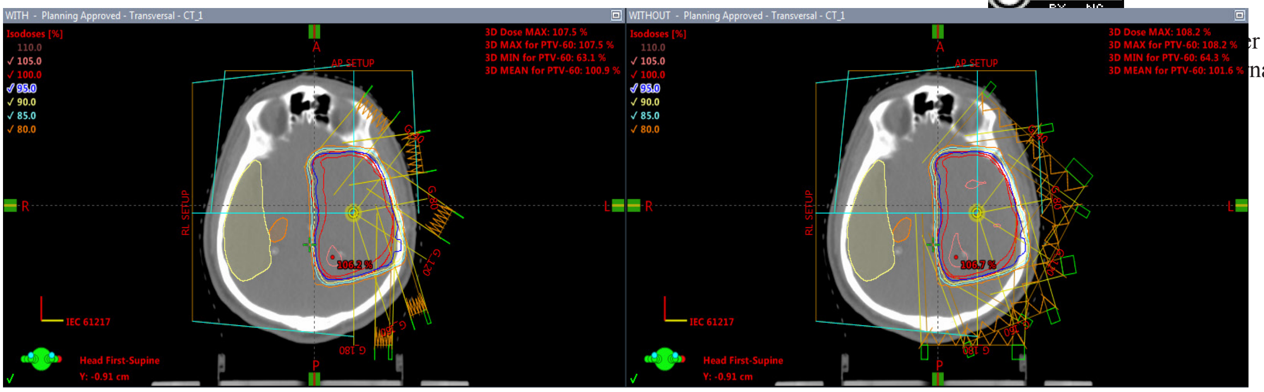

Figure 1. The Dose Distribution of (1) JTT Plan and (2) SJT Plan.

JTT and SJT plans whose graphical representation is shown in Figure 2. These data give more significant Δ values and corresponding P values which emphasize the effect of jaw tracking to reduce the dose to normal tissues and OARs. The significant P values obtained among OARs are 0.0224 for brainstem, 0.0017 for RT optic nerve, and 0.0001 for LT optic nerve, 0.0040 optic chiasm with their Δ values as 0.54, 0.54, 0.52, and 0.59 respectively. Similarly, the healthy tissues showed significant Δ values of 0.19, 0.59, 0.25 with their mean dose, V5, V30 parameters and their corresponding P values as 0.0115, 0.0067, 0.0125 respectively.

From the data obtained with the technical characters of JTT and SJT plans, it can be inferred that there is not much difference in the total MUs and treatment time of both plans for all patients under study as their P values are not significant apart from their Δ values of 8.61 and 0.097 respectively.

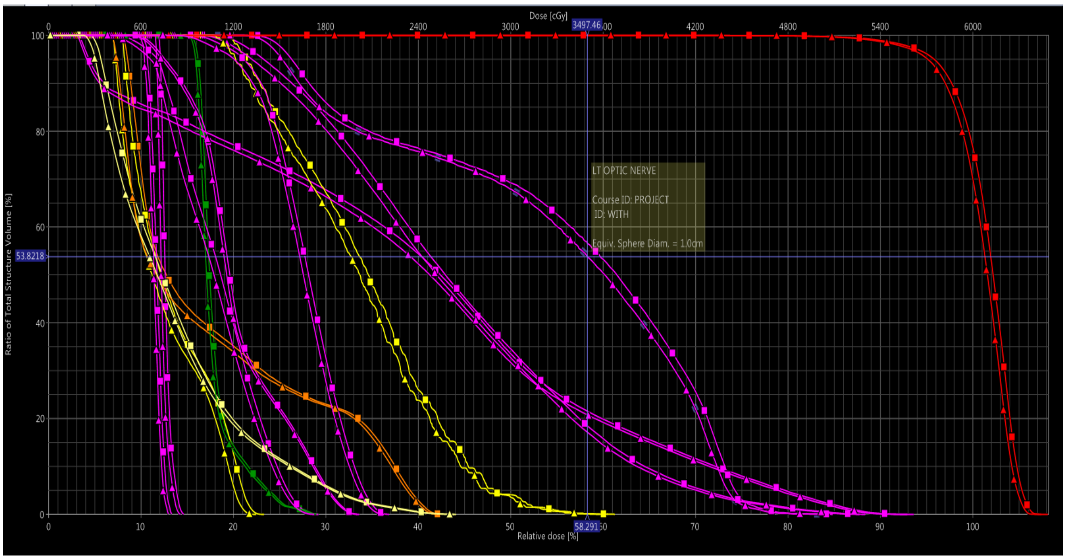

Figure 2. The DVH Comparison of PTV and OARs of a Patient for Both JTT and SJT Plans

Table 4. Technical Characteristics of Static Jaw and Jaw Tracking Plans

Technical Parameters	Jaw Tracking Technique (JTT)	Static Jaw Technique (SJT)	Δ	P-Value
MU	639.28±254.5	630.67±243.6	8.61	0.103
TT	3.805±1.13	3.708±0.94	0.097	0.215

Δ, Difference between static jaw technique (SJT) and jaw tracking technique (JTT) plan.

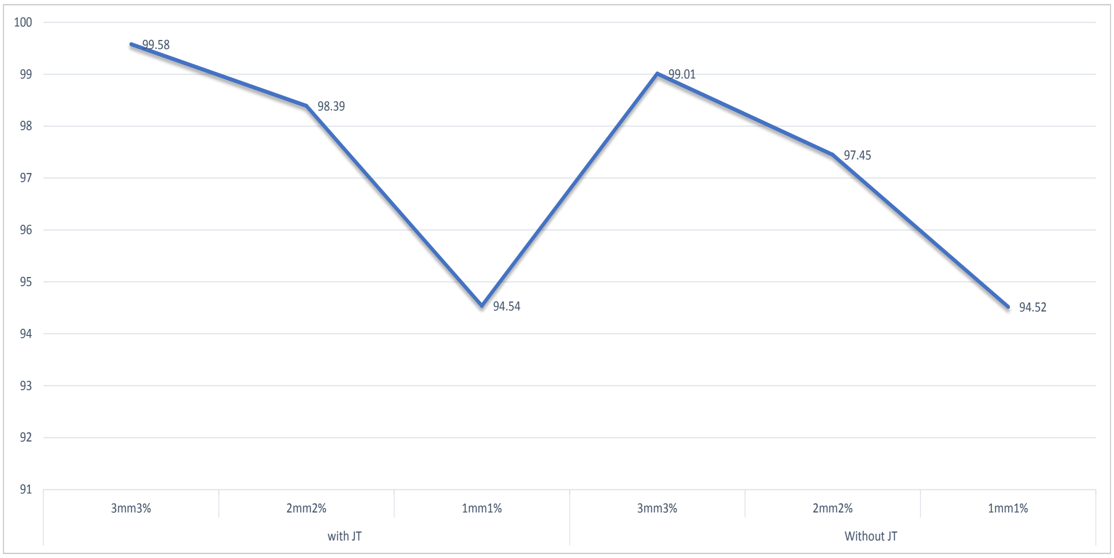

Figure 3. Gamma Results for Jaw Tracking Technique and Static Jaw Technique Plans

Figure 1 shows the graphical representation of gamma analysis results. From the plan verification results of JTT and SJT plans with the gamma evaluation method using portal dosimetry, it was concluded that JTT plans showed better passing results of 99.58±0.5, 98.39±0.8 and 94.54±1.1 with 3mm/3%, 2mm/2% and 1mm/1% gamma analysis criteria when compared to the SJT plan values of 99.01±0.8, 97.45±0.8 and 94.52±1.3 respectively. Their P values were significant in the order of 0.0028 and 0.0005 for 3mm/3% and 2mm/2% criteria which in turn shows the importance of the jaw tracking technique.

The dose distributions of both plans and the DVH comparison of PTV, OARs of a patient for both JTT and SJT plans are shown in Figure 1 and Figure 2 respectively.

Table 2, Table 3 and Table 4 gives the mean±standard deviation values along with their Δ and P values of different parameters analyzed from the DVH of PTV, OARs and technical characteristics of the plan.

Discussion

The findings in the study very well shows the dosimetric importance of jaw tracking in radiotherapy practice and the importance of implementing the same by showing its impact on plan PTV parameters as well as OARs doses. In a study, it is specified that the shape of target and location of the cord in spine radiosurgery makes it a perfect site for using jaw tracking and

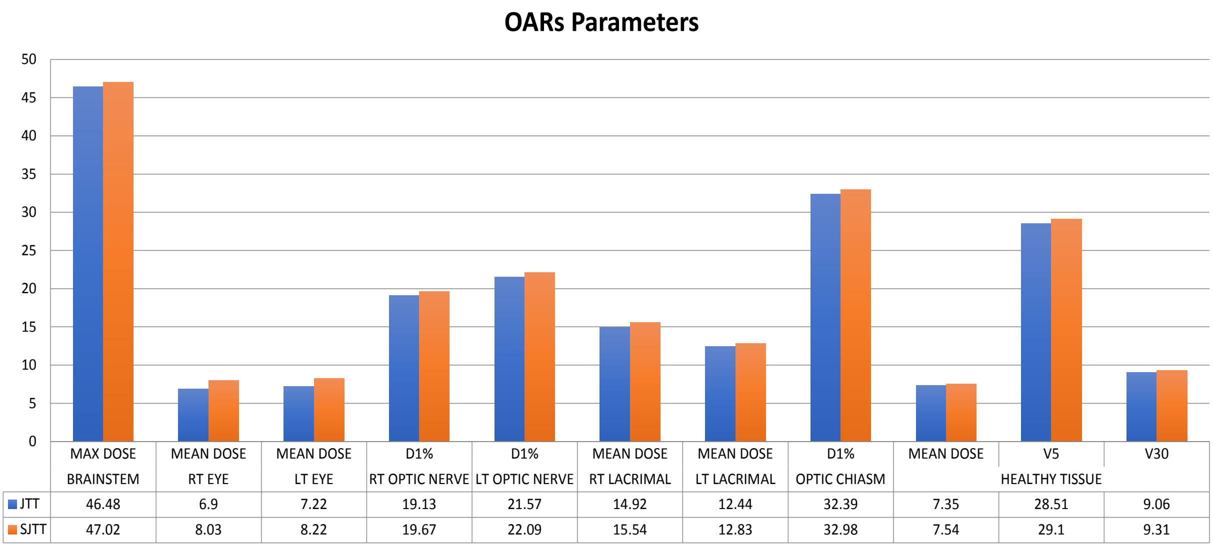

Figure 4. The Graphical Comparison of Dosimetric Parameters of OARs

recommended that for efficient tracking, the jaw speed has to be greater or equal to that of MLC (Snyder et al., 2015). The study also proved that adding the jaw tracking technique decreases the spinal cord dose in both IMRT and Volumetric Modulated Arc Therapy (VMAT) techniques where it was more decreased in IMRT when compared to VMAT plans. Here the present study also chose the IMRT technique for the retrospective Glioma cases that are little prone to patient motion within the immobilization device during treatment. Our study results shows significant P values while comparing SJT and JTT plans and the plan evaluation parameters of PTV such as CI95%, HI95%, CN95%, COVI, DGI and other dose values like D2%, D98%, D50% and D80%, clearly defines the importance of Jaw tracking technique to achieve better values with the parameters and thereby accomplishing our aim of precise radiation delivery to target tissues while sparing the OARs. This is contrary to the theoretical computation of increased PTV dose with the usage of the jaw tracking technique (Schmidhalter et al., 2007).

Similarly, the impact of jaw tracking on OARs and its significance is evaluated in many studies whereas our study added its effect on Healthy tissue volumes apart from other OARs on the site. In our study, the mean doses of various organs surrounding the target volume are evaluated for the prediction of the probability of radiation toxicity as in many studies the mean dose of OARs has been widely used (Bradley et al., 2007; Kong et al., 2006). Another study inferred that V5, V10 and V20 of OARs can be lowered by 2% using the jaw tracking technique (Joy et al., 2012). In our study, almost all OARs showed a remarkable reduction in their different dose values and dose volumes studied such as maximum dose, mean dose, D1%, V5 and V30, after adding jaw tracking technique to the plans with their very significant P values. This result is of high clinical importance as stated in a study that the risk of radiation induced secondary malignancies is of major concern which is related to low dose exposure of normal tissues during IMRT (Chera et al., 2009).

Zhongsu Feng stated in his study that adding JTT to the treatment plans is of clinical importance to the patients with local recurrent lesions within a previously irradiated area and also for patients with complex and large targets that are lying close to very radio-sensitive organs to be spared such as gonad or lens (Feng et al., 2015). Even our study of Glioma cases is a site which is availed with the most number of critical organs of high sensitivity and concern. As this site is least prone to dose delivery errors from patient immobilization, the effect of jaw tracking will be a very advantageous tool for the critical organs to keep their exposure to the least values possible. This in turn helps to lower the risk of radiation injury such as cataracts as mentioned by one of the studies. In the case of plans utilizing higher photon energies the jaw tracking will be very beneficial as the increased radiation transmission through MLCs in such high energy plans could be very well blocked by the jaws (Mohan et al., 2008). As stated by many findings, the jaw tracking technique helps not only to reduce the risks of secondary radiogenic cancer and acute or late toxicity but also helps to attain potential target dose escalation as a trade-off for greater control of tumor (Wu et al., 2016)

One of the studies explained the achievement of jaw tracking in reducing the normal lung and OAR dose in SBRT (Stereotactic Body Radiation Therapy) procedures without making any significant change in treatment time, which can potentially lower the risk of acute or late toxicity (Pokhrelet al., 2019). Likewise, our study results from Table 3 show that the least difference in MUs and treatment time between SJT and JTT plans along with their insignificant P values makes JTT plans more relevant over SJT plans to be used in radiotherapy apart from the advantage of sparing OARs while achieving better tumor control.

Certain studies have done plan verification and dose measurements with their results of gamma pass rate for 3% and 2mm as >95% (Snyder et al., 2015). But in our study, the gamma results of SJT and JTT plans from figure 1 shows that JTT plans give a good agreement of dose measurements with the TPS calculated values for all criteria of analysis (3%/3mm, 2%/2mm and 1%/1mm) when compared to the SJT plans. In JTT plans, the jaw is very near to the PTV margin and hence there is less scattered radiation as well as less inter and intra leaf radiation which could make it possible to have nearly equal TPS and machine fluence. This again gives another point of advantage with the jaw tracking technique to be implemented in radiotherapy execution practice.

In conclusion, the findings in this study emphasize the importance of using JTT technique in the radiotherapy treatment plans and the importance of treatment execution in all centres either by upgradation or installation of their units. This technique will be an add-on benefit to paediatric patients as it lowers the risk of secondary radiogenic cancers and acute or late toxicity by reducing the OAR doses. Moreover, this technique contributes to deliver quality treatment plans with better target coverage and tumor control without any significant change in MUs and treatment time when compared to the SJT technique. The plan evaluation results also showed that for JTT plans, the dose measurement values agreed well with that of TPS calculated dose values when compared to the SJT plans which will again enhance the dosimetric importance of implementing JTT technique in radiation therapy.

Author Contribution Statement

The authors confirm contribution to the paper as follows: Study conception and design: Hridya V T and Aswathi Raj, data collection analysis and interpretation of results: Hridya V T, draft manuscript preparation: Hridya V T. All authors reviewed the results and approved the final version of the manuscript.

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Ethical Standards

These articles don’t carry any studies on human participants or animals by any of the authors.

Financial Disclosure

The authors didn't receive any kind of financial support from any of the organization

Data Availability

Research Data is not shared.

Conflict of Interest

All authors declare no conflict of interest.

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