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Analysis of Quality Parameters of Radiation Treatment Plans Using SRS (Stereotactic Radiosurgery) and SRT (Stereotactic Radiotherapy) – A Single Institution Six Year Experience

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Abstract **Original Research Article**

Aim: The study's aims were to assess key plan quality indicators, including the Conformity Index, Gradient Index, and Homogeneity Index, which had previously been evaluated using isodose lines and DVH.

Materials and Methods: We reviewed the treatment plans for 37 retrospective cases that used the TrueBeam STx linac for stereotactic radiosurgery (SRS) and stereotactic radiotherapy (SRT) between 2019 and 2024. Treatment plans were evaluated using the following plan quality parameters suggested by Radiation Therapy Oncology Group [RTOG] such as Quality of Coverage [Q_{RTOG}], Homogeneity Index [HI_{RTOG}] and Conformity Index [CI_{RTOG}] Apart from that, Paddick's Conformity Index [$CI_{Paddick}$], Lomax Conformity Index [CI_{Lomax}], New Conformity Index, Gradient Measure (GM), Gradient Index (GI), R50%, and Equivalent Fall-off Distance [EFOD].

Results: The percentage accuracies of CI_{RTOG}, $CI_{Paddick}$, CI_{Lomax} that are as per the protocol are 83.7%, 67.6%, 87.5%, respectively. It was found that the plan quality metrics are independent of target volumes and shape.

Conclusion: On analysis, all the plan quality parameters of patient treatment plans which were treated earlier was found to be within the protocol.

Keywords: Stereotactic Radiotherapy, Conformity Index, Gradient Index, Gradient Measure, Equivalent Fall-Off Distance.

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1. INTRODUCTION

Brain metastases are the most common intracranial tumors in adults, accounting for significantly more than one-half of brain tumors. Symptomatic brain metastases occur in 8%-10% of persons with cancer, primarily from lung (40%-50%), breast (15%-25%), or melanoma (5%-20%) cancers.[1,2] Radiation therapy, including intensity-modulated radiation therapy (IMRT) and stereotactic radiosurgery (SRS), Stereotactic Radiotherapy (SRT) is common for both benign and malignant brain tumors. It plays a crucial role in managing brain tumors, improving outcomes, prolonging survival, and enhancing quality of life.

Introduced by Swedish neurosurgeon Lars Leksell in the 1960s, the Gamma Knife was one of the earliest devices used for SRS which utilized cobalt-60 sources arranged in a hemispherical configuration. Linac technology, initially developed for conventional radiation therapy, underwent significant advancements that made it suitable for SRS applications. The development of Multileaf collimators (MLCs) allowed LINACs to shape radiation beams dynamically, enabling precise dose delivery to complex target volumes.

SRS is a technique used to deliver high radiation to a focal target in a single fraction, while minimizing the dose to normal brain tissue.[3] Whereas SRT involves fractionating the required dose into multiple doses, requiring high accuracy and a steep dose gradient to ensure the tumour receives a sufficient dose while protecting surrounding normal tissues, as each dose in a single treatment is extremely large.[4]

Clinicians typically do slice-by-slice visual verification of prescription isodose lines to confirm that they meet the projected target coverage. It is typical to establish many treatment plans for the same patient, with essentially identical dose distributions. This type of situation is often difficult for clinicians because they are unsure of what basis to approve the treatment plan. This needs the creation of a technology capable of integrating this data more efficiently in order to objectively assess the quality of treatment regimens. The conformity index, homogeneity index, and gradient index are among the measures used to analyse treatment plans. Our institute adopted the former, and in this study, we will examine the CI, GI, and homogeneity index, which were previously analysed using isodose lines and DVH.

2. MATERIALS AND METHODS

2.1 Patients

The study comprised 37 individuals who have been treated with linac for SRS/SRT since 2019. Primary lesions were associated with diseases such as lung cancer, breast cancer, renal carcinoma, and thyroid cancer. This study also investigated different forms of brain tumours, including schwannoma. This study includes tumours ranging in size from 1.16 to 44.1cc, with a male-to-female ratio of 22 to 15. All of the studies involved a single lesion.

2.2 Patient Set-Up and Simulation

Each patient was subjected to a simulation utilising Philips Truflight PET computed tomography with a dedicated protocol and slice thicknesses of 0.5/ 1 mm. The simulation was carried out in supine position with a hybrid thermoplastic mask designed specifically for stereotactic treatment.

2.3 Treatment Planning

All patient's images were imported to the Treatment Planning System (TPS) and was merged with MRI images. The target and critical structure delineation was done using Varian Somavision 15.6. Gross tumor volume (GTV) was drawn on the CT images as per ICRU report 83. Planning target volume (PTV) was created by a 3-dimensional 0-2 mm expansion around GTV to account for the imaging fusion uncertainty, contour variations, setup errors and possible patient movements. Dose controlling shells were created around the PTV. The isocenter was placed in the geometric centre of the GTV as determined by the TPS. The arcs and collimator angles are customized for each patient to ensure optimal fit. Depending on the position of the tumor, half arc, full arc and non-coplanar arcs are employed.

The employed linac was a Varian capable of delivering flattened photon beams with energies of 6 MV, 10 MV, and 15 MV, as well as unflattened photon beams with energies of 6 MV and 10 MV. This unit is outfitted with a high-definition multi-leaf collimator (HDMLC), which has 60 pairs of 2.5mm leaf width in the middle region of 8 cm and the remaining 5mm leaf width in the perimeter. Some patients are treated with Flattening Filter (FF) beams, while others receive Flattening Filter Free (FFF) treatment regimens.

2.4 Dosimetric Evaluation

The plan quality metrics used in this study are as follows:

a) A conformity index, CI_{RTOG} is a key dosimetric parameter proposed by the Radiation Therapy Oncology Group [RTOG] for determining how well a radiosurgical dose distribution fits a target volume. The CI is the ratio of the prescription isodose volume (PIV) divided by the target volume (TV)

$$CI_{RTOG}=PIV/TV \quad (1)$$

Plans with conformance index values between 1.0 and 2.0 do not deviate from the RTOG protocol. Minor deviations are defined as conformity index values ranging from 0.9 to 1, and 2.0 to 2.5. Plans with values less than 0.9 but larger than 2.5 are considered as major deviations.[5] ICRU report 83 advocated the use of CI because it helps determine the degree of congruence between intended target volume and prescribed isodose.[6]

b) Quality of coverage, Q is the second metric developed by RTOG to evaluate SRS plans.

$$Q= I_{min}/RI \quad (2)$$

Where I_{min} is the minimum dose in target and RI is the prescription. The case is considered per protocol, when 90% of the prescription isodose line completely covers the target. If 90% does not, but 80% does, it's a minor deviation. If 80% doesn't, it's a major acceptable deviation.[5]

c) Homogeneity Index (HI) is an objective tool to analyze the uniformity of dose distribution in the target volume. The definition of Homogeneity Index (HI) as per ICRU report 83 was suggested

$$HI = (D_{2\%} - D_{98\%})/D_{50\%} \quad (3)$$

where D_2 and D_{98} are the dose received by 2% and 98% of the target volume respectively. D_{50} are the dose received by 50% of the target volume.[15,16] A HI of zero indicates that dose distribution is almost homogenous.[15,16] HI is included in this analysis even though it is not quantified in SRS/SRT.

d) Paddick's Conformity Index

Another alternative to the RTOG conformity index is the Paddick's conformity Index, $CI_{Paddick}$, as proposed by Paddick in 2000. It is defined as

$$CI_{Paddick} = TV_{PI} /PI \text{ X } TV_{PI} /TV = TV_{PI}^{\,2} /PI \text{ X } TV \quad (4)$$

where TV_{PI} is the target volume within the prescribed isodose volume. A perfect plan would have TV_{PI}=TV=PI and yield a $CI_{Paddick}$ of 1.0 as well as a PITV of 1.0.[8]

e) New Conformity Index

It is modified by Nakamura et al. in 2001 by inversing the formulation of Paddick's conformity index. This index has the same limitation as paddick's conformity index.[6]

$$\text{New Conformity index} = TV \times PIV/(TV_{PIV})^2 \quad (5)$$

ICRU Report No. 91 was suggested the above equation.[17] The ideal value of a new conformity index will be less than 1.18.[15]

f) Lomax Conformity Index
In order to overcome Another often-used metric of radiosurgery conformity was proposed by Lomax and Scheib in 2003. It is the ratio of the volume within the target irradiated to at least the prescription isodose over the total volume enclosed by the prescription isodose.[7]

$$CI_{Lomax} = V_{T,pi} / V_{pi} \quad (6)$$

$V_{T,pi}$, the volume within the target irradiated to at least the prescription isodose. V_{pi}, total volume enclosed by prescription isodose. A geographic miss of the target cannot give a perfect score. This ratio gives a value ranging from 0 to 1 (no conformity to perfect conformation). CI value close to unity is when the plan is ideal and lower the ratio, poorer the conformity.[7]

g) Gradient Measure
Gradient measure is defined as the difference between the equivalent sphere radius of the prescription and half-prescription isodoses.

h) Gradient Index
The GI is an effective tool that can be used to objectively measure this dose falloff outside the target. It can also use to demonstrate the optimal prescription isodose.[9] The gradient index is the ratio of the volume of half the prescribed isodose to the volume of the prescription isodose.[9]

$$GI = V_{50\%}/V_{100\%} \quad (7)$$

Equation is recommended by ICRU- 91 for reporting as gradient index in SRS/SRT plans.

i) Equivalent Fall- Off Distance (EFOD)
It is defined as the equivalent radial distance measured between two isodose lines. the dose fall-off rate can also act as a measuring index for plan comparison, because a fast dose fall-off rate is often a requirement for radiosurgery in order to minimize the risk of radiation damage to the surrounding structures.[10]

Treatment volume ratio (TVR) is defined as a useful measuring index for plan

evaluation, where TVR is the ratio of target volume to the treatment volume.[10]

$$TVR = TV/ V\,RI \quad (8)$$

Where TV is the target volume and VRI is the irradiated volume. The TVR can help the user how much normal tissue would have received the prescribed dose.[10,11]

$$EFOD = (3\sqrt{TVR1} - 3\sqrt{TVR2}) * R \quad (9)$$

Where R is the equivalent radius of the target volume, and TVR 1 and TVR 2 are the TVRs for 100% and 50% isodose, respectively.

j) R50%
R50% is a common metric for intermediate dose spill and is defined in RTOG 0915 as the ratio of 50% prescription isodose cloud volume ($V_{IDC50\%}$) to the planning target volume (V_{PTV}).[12]

$$R50\% = V_{IDC\ 50\%} / V_{PTV} \quad (10)$$

RESULT

a) RTOG Conformity Index (CI_{RTOG})

Figure 1 depicts a graph of the RTOG Conformity Index versus Target Volume for the 37 brain cases in the database. Plans with smaller target volume often had higher conformity indices, but conformity indices for larger volumes stayed relatively constant.[13]

The maximum CI value of 1.7 occurred for a plan with target volume 0f 6.84 cc. The average conformity index value whose target volumes smaller than 3 cm^3 is 1.16. For volumes between 3-8 cm^3 had an average CI value of 1.2. The overall conformity index average was found to be 1.1. Out of 37 targets examined, 5(13.51%) had minor deviations and 1 (2.7%) had major deviations of 0.79.

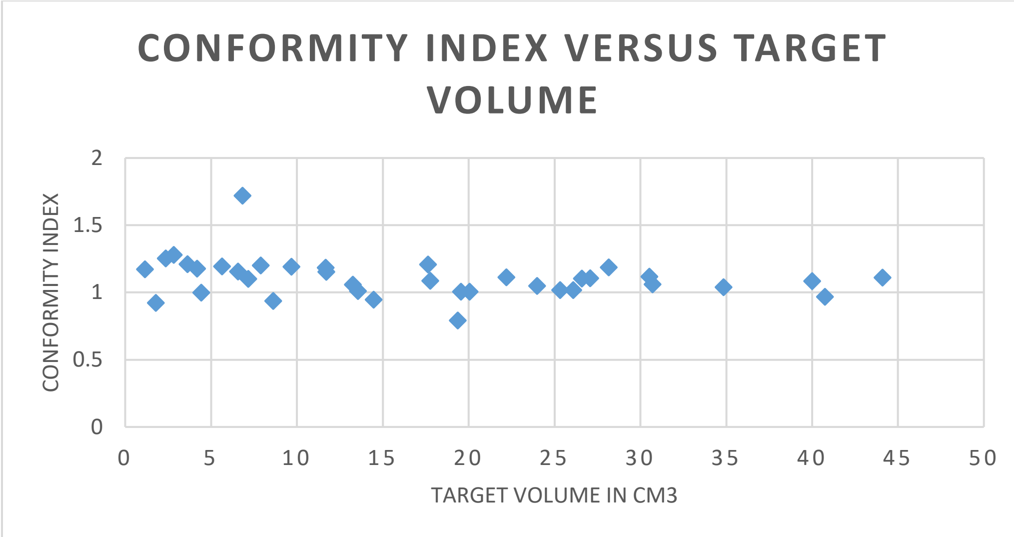

Fig 1: Conformity Index as a function of target volume

b) Quality of coverage

A graph of RTOG quality of coverage versus target volume can be seen in fig. 2. The maximum and minimum quality of coverage value was 0.99 and 0.71 respectively. The average quality of coverage values was 0.90.

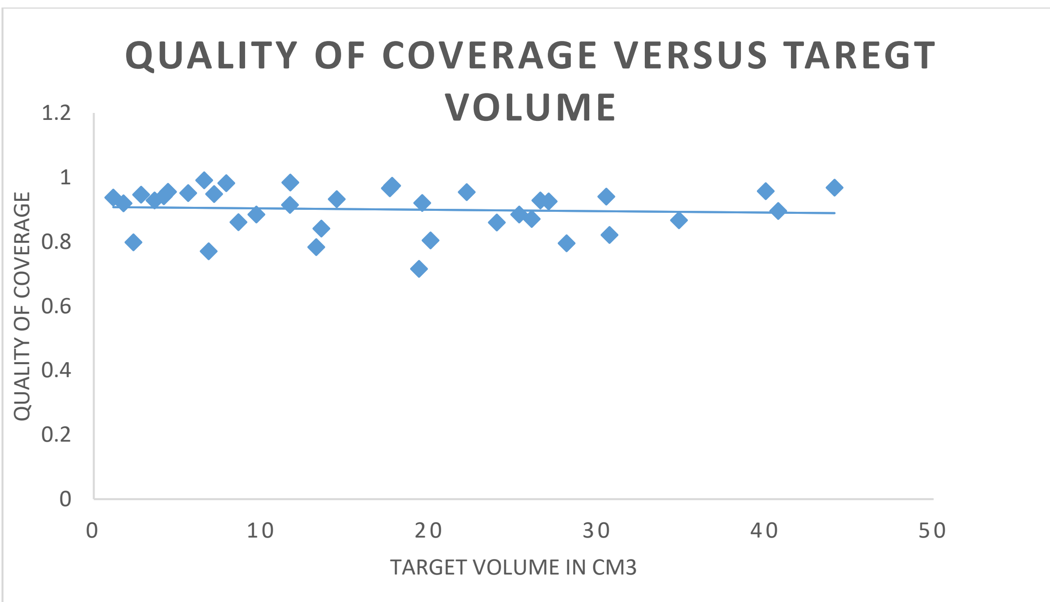

Fig.2 Quality of coverage versus Target volume

The quality of coverage for 22(59.5%) of the plans was as per RTOG guidelines where 10 (27%) of the plans showed minor deviation from the RTOG protocol (minimum dose in target is 80%–90% of the prescription isodose) and 5 (13.5%) of plans showed major deviations (i.e., have a minimum dose in target less than 80% of the prescription isodose).

c) Homogeneity index (HIRTOG)

A plot of homogeneity index versus target volume is given in fig.3. HI RTOG was as per guidelines for all the plans. The homogeneity index ranges from 0.04 to 0.5 which is as per the guidelines. The average homogeneity index was 0.11. $(D_2 - D_{98})/D_{50}$ indicate a more homogeneous dose distribution.[14] No other index will be able to provide an indication of the maximum dose within the target.[11]

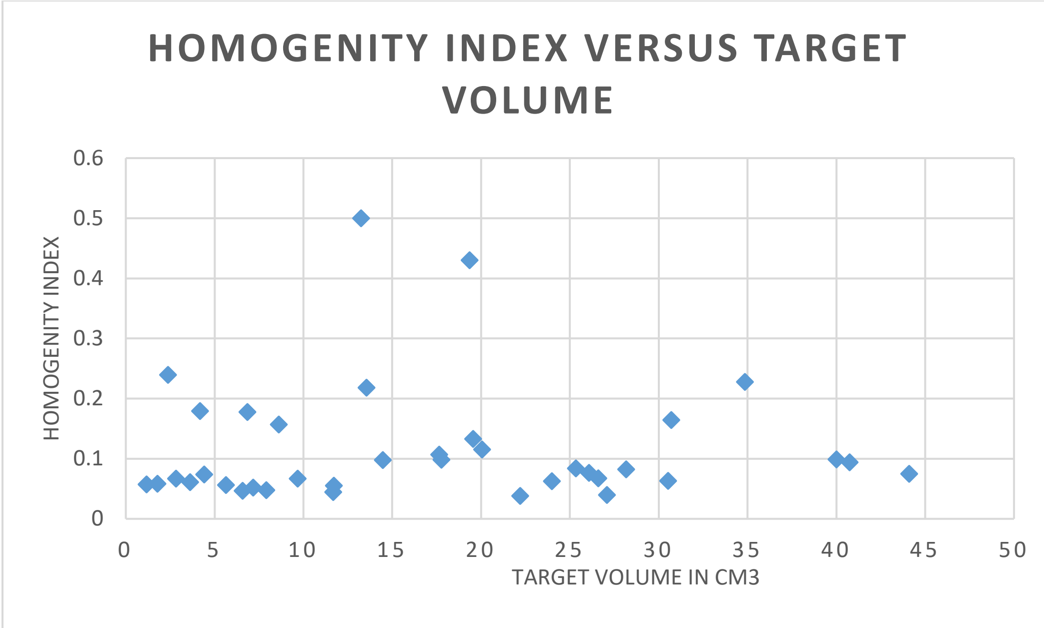

Fig.3 Homogeneity index versus target volume

Alternative indices

Paddick's conformity index ($CI_{Paddick}$)

The Paddick's conformity index was plotted against target volume is shown in fig.4. According to our study paddick's conformity index is independent of target volume. The average Paddick's index was 0.74. 32.4% of plan had a $CI_{Paddick}$ Value lesser than 0.7 and 67.6 % of plan had a $CI_{Paddick}$ value greater the 0.7.

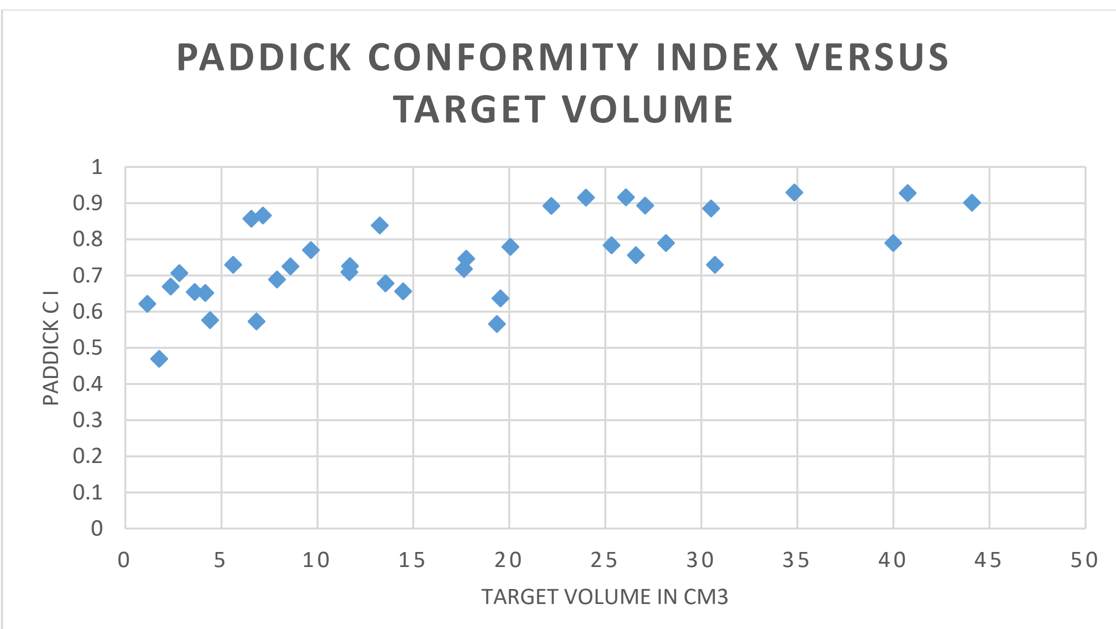

Fig.4 Paddick's conformity in dex versus target volume

New Conformity Index

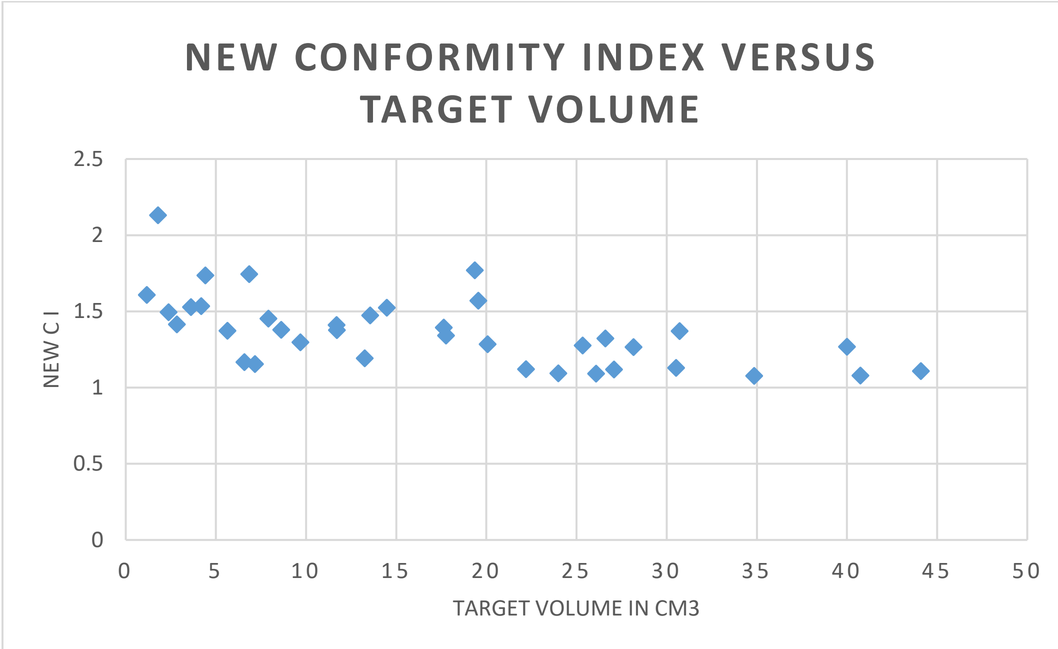

Fig.5 New conformity index versus target volume

Here fig.5 shows a scatter plot of new conformity against target volume. Here the new conformity index had an average value of 1.36. whereas an ideal new conformity index is 1.18. The minimum new conformity index value was 1.07 and maximum value was 2.13.

Lomax Conformity Index (CI_{LOMAX})

A plot of Salt-Lomax conformity index for the database is given in fig.6. the plan is analyzed using our preferred CI (Eq.5), the mean CI is 0.90. A total of 62.1% or 23 of the 37 targets had a value between 0.9 to 1. For 87.5% of cases, the CI_{Lomax} and a value greater than 0.8. only 5 cases were less than 0.8.

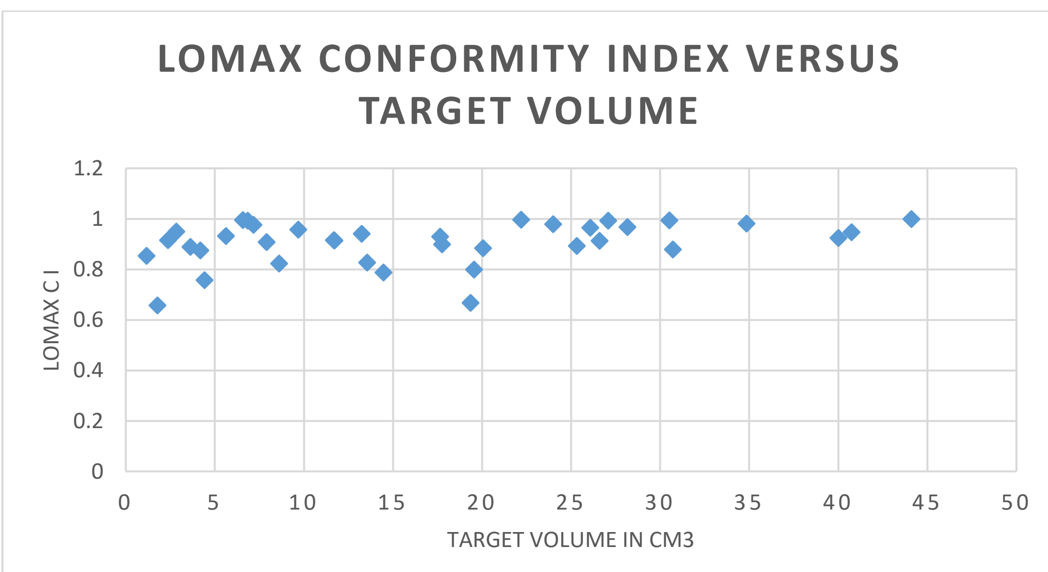

Fig.6 Lomax conformity index versus target volume

Gradient Index

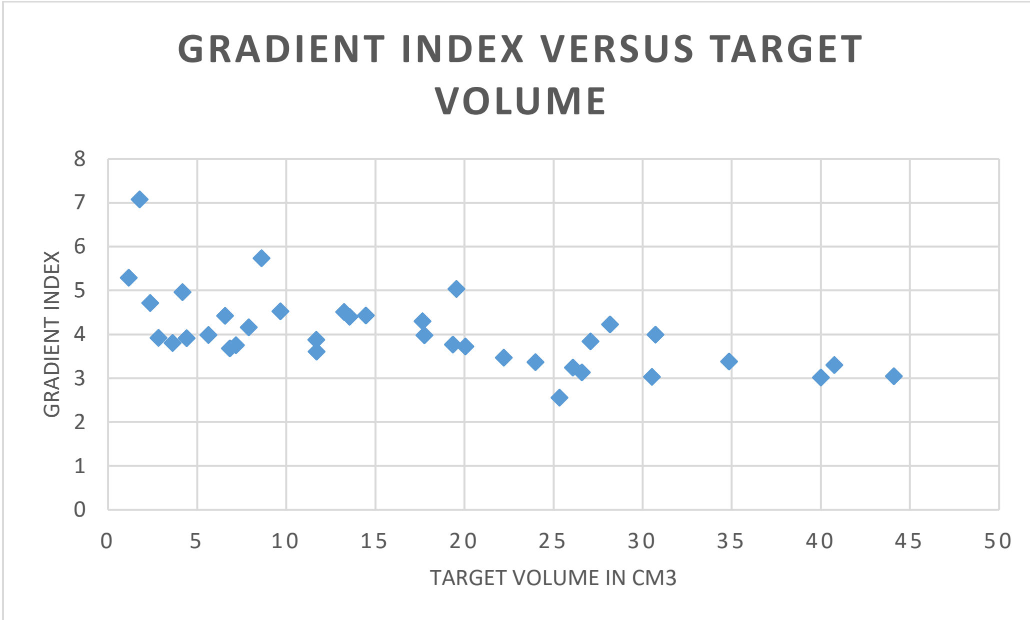

Fig.7 Gradient index versus target volume

Here fig.7 shows the scatter plot of gradient index versus target volume. The gradient index value ranges from 2.56 to 7.07. The average gradient index is 4.03. The GI is intended to distinguish between these plans with same conformity but different dose gradients.[9]

Effective fall-off distance (EFOD)

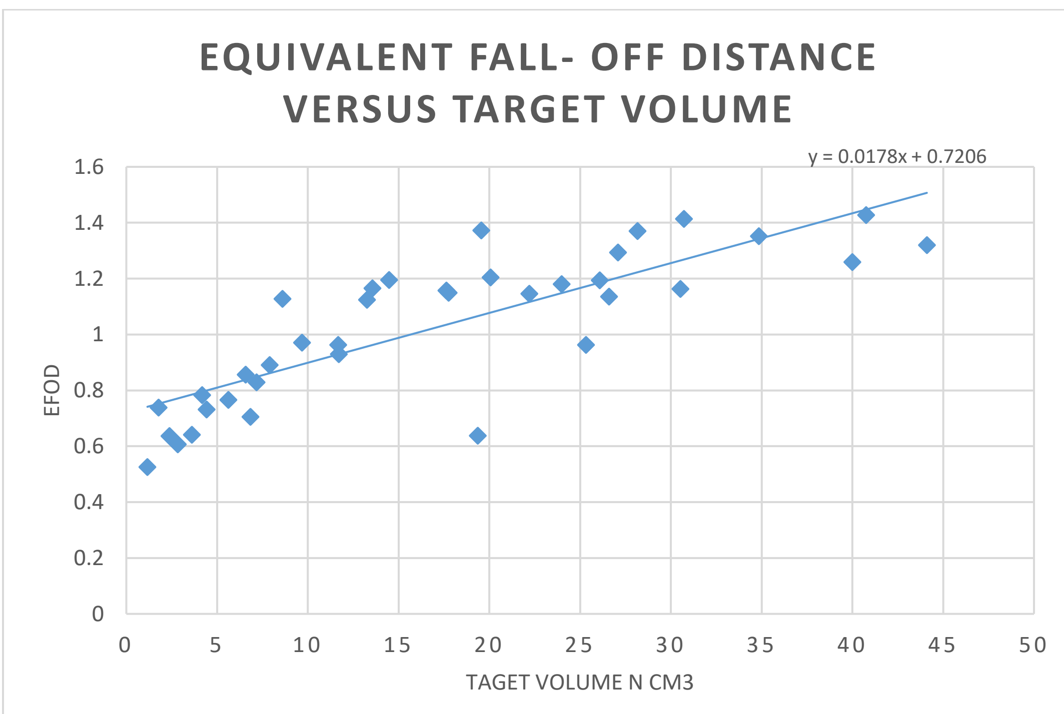

Fig.8 Equivalent fall off distance (EFOD) versus target volume

Fig.8 shows the scatter plot of EFOD versus target volume. In this study, it was observed that for 45.9% of cases, the EFOD ranged from 0.5 mm to 1mm. for 54.05% of cases the EFOD ranged from 1mm to 2mm. Here a dose fall off is observed for smaller targets. EFOD increases linearly with the target volume.

Gradient Measure

The gradient measure was plotted against target volume is shown in fig.9. The

observed gradient measure ranges from 0.56 to 2.04, and the average gradient

measure value was 1.

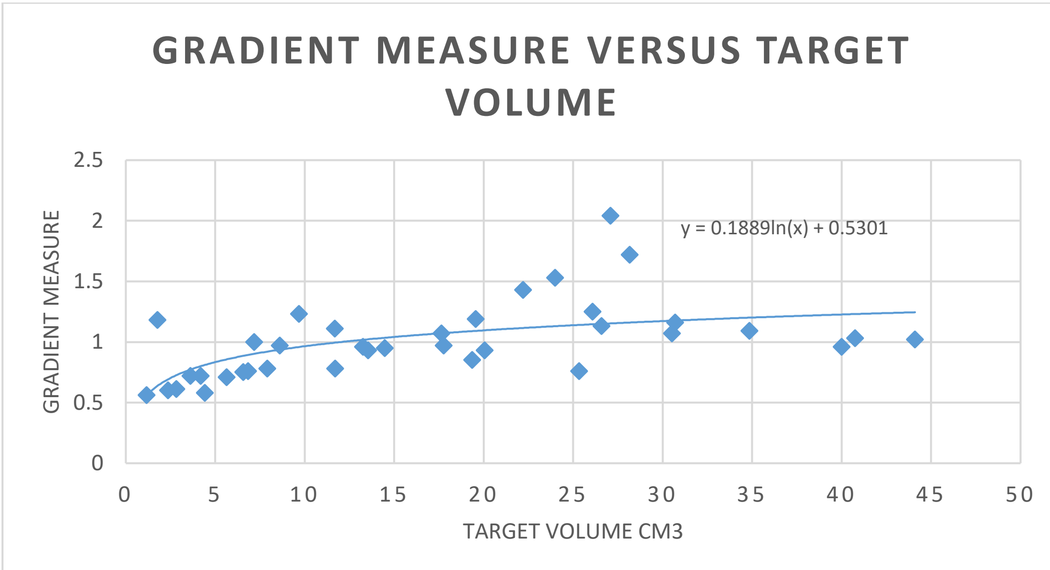

Fig.9 Gradient measure versus target volume

R50%

Here fig.10 shows a plot of R50% versus target volumes. Values of R50% for 37 target volumes ranges from 2.60 to 6.52. the average R50% values 4.45. It is observed that the R50% decrease as the volume increases.

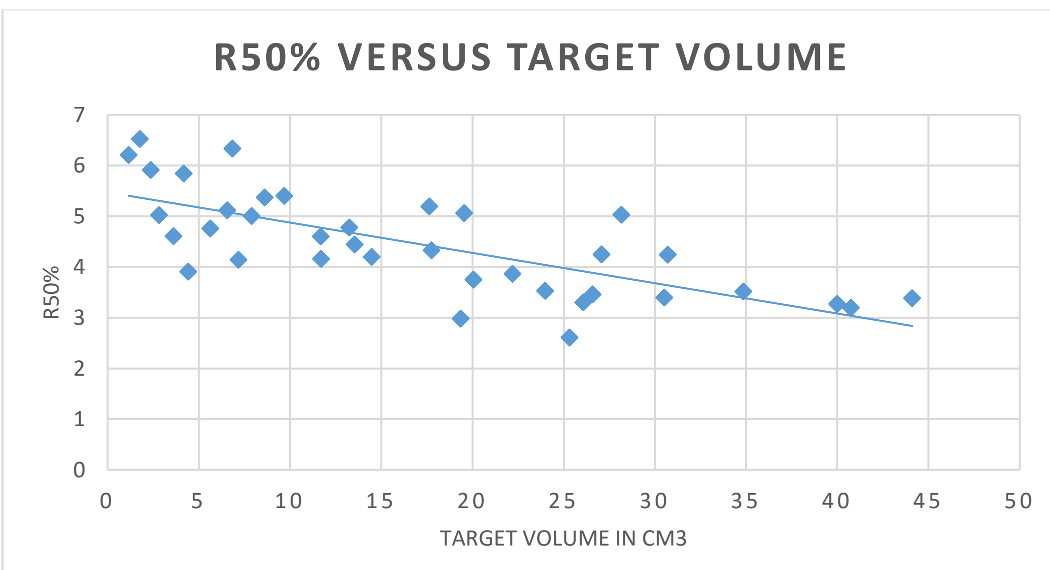

Fig.10 R50% versus target volum e

4. DISCUSSION

The conformity index, represents an attempt to measure objectively how well the distribution of radiation follows the shape of the radiosurgical target.[9]

In this study the overall RTOG conformity index average for the 37 targets was found to be 1.10. The conformity index for the 170 targets found by Julia Stanley was 1.98.[13] Out of Thirty-seven, thirty-two (83.7%) of the targets met the conformity index values to be classified as "per protocol" by RTOG. The conformity index found by N J. Lomax and S. G. Scheib was 1.24.[7] Two independent measures of the quality of the absorbed dose distribution are dose homogeneity and dose conformity.[16]

The analysis of thirty-seven targets conformity index CI_{Lomax} proposed by Lomax and Scheib values ranges from 0.65 to 1. About 87.5% of cases, the CI_{Lomax} had a value greater than 0.8. only 5 cases were less than 0.8, that is a major deviation from RTOG protocol. Lomax and Scheib suggested Seventy-five percent of targets have a CI value of greater than 0.6.[7] If the volumes less than 1 cm^3 are excluded from analysis, 92% of all plans have a CI > 0.6.

In our study, the average paddick's index was 0.74. The 32.4% of plan had a $CI_{Paddick}$ Value lesser than 0.7 and 67.6% of plan had a $CI_{Paddick}$ value greater the 0.7. Van't Riet et al suggested that when planning target volume is considered, the targets have a mean CN 0.65.[18]

In 2003, Jackie Wu reported that the existing conformity indices depended on target size and shape complexity. Author proved that both volume and shape complexity can have significant effects on conformity values.[6]

In our study the value of conformity index, is independent of target volume and shape.

CONCLUSION

An institutional study was conducted to evaluate the quality metrics of treatment plans in stereotactic radiosurgery. The clinically approved treatment plans were analyzed by dose distribution and DVH and evaluated for the RTOG conformity index, Paddick's CI, Salt-Lomax conformity, gradient index, gradient measure, R50%, EFOD, etc. All the plan quality parameters were within the protocol limits for the treatment plans which were analysed using Dose volume histogram and dose distribution.

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