Evaluation of Plan Quality Metrics in Stereotactic Radiosurgery/Radiotherapy in the Treatment Plans of Arteriovenous Malformations

Sharika Venugopal Menon, Raghukumar Paramu, Saju Bhasi, Raghuram Kesavan Nair

Division of Radiation Physics, Regional Cancer Centre, Thiruvananthapuram, Kerala, India

Abstract

Aim: Several plan quality metrics are available for the evaluation of stereotactic radiosurgery/radiotherapy plans. This is a retrospective analysis of 60 clinical treatment plans of arteriovenous malformation (AVM) patients to study clinical usefulness of selected plan quality metrics. **Materials and Methods:** The treatment coverage parameters Radiation Therapy Oncology Group (RTOG) Conformity Index (CI_{RTOG}), RTOG Quality of Coverage (Q_{RTOG}), RTOG Homogeneity Index (HI_{RTOG}), Lomax Conformity Index (CI_{Lomax}), Paddick's Conformity Index ($CI_{Paddick}$), and dose gradient parameters Paddick's Gradient Index ($GI_{Paddick}$) and Equivalent Fall-off Distance (EFOD) were calculated for the cohort of patients. Before analyzing patient plans, the influence of calculation grid size on selected plan quality metrics was studied on spherical targets. **Results:** It was found that the plan quality metrics are independent of calculation grid size ≤ 2 mm. EFOD was found to increase linearly with increase in target volume, and a linear fit equation was obtained. **Conclusions:** The analysis shows that RTOG indices and EFOD would suffice for routine clinical radiosurgical treatment plan evaluation if a dose distribution is available for visual inspection.

Keywords: Arteriovenous malformations, conformity indices, gradient indices, plan evaluation, stereotactic radiosurgery

INTRODUCTION

A single fraction radiation therapy procedure is called stereotactic radiosurgery (SRS). It uses a combination of stereotactic apparatus and small radiation beams to treat intracranial lesions with minimal damage to surrounding normal structures.[1,2]

In SRS, the total prescribed dose is in the order of 10–50 Gy to small targets having typical volumes ranging from 1 to 35 cm³. SRS requires a positional accuracy of ±1 mm and a dose delivery accuracy of ±5%.[3]

Improvements in dosimetry software permitted three-dimensional (3D) dose calculations and dose distributions that could be viewed from any angle. This 3D dose distribution could be quantified by dose-volume histograms (DVHs).[4,5] It is a plot of volume versus dose (volume on ordinate and dose on abscissa) of a particular delineated tissue and is also used for plan evaluation. The maximum, minimum, mean, and modal doses could be determined with DVHs. A DVH can also provide the dose received by a certain volume of tissue. This tool helps to compare rival plans and also ensure that normal tissue does not exceed tolerance doses.[5] The disadvantage of DVH is that it does not provide spatial information.[4]

SRS plans require a high degree of conformity to minimize damage to surrounding normal tissue. If this conformity is not achievable, then dose has to be fractionated to minimize damage to normal tissue.[6]

Routinely, the quality of an SRS plan can be evaluated using dose distribution and DVH. In addition, plan quality metrics have been proposed by many authors to objectively measure the quality of a SRS treatment plan. These metrics

How to cite this article: Menon SV, Paramu R, Bhasi S, Nair RK. Evaluation of plan quality metrics in stereotactic radiosurgery/radiotherapy in the treatment plans of arteriovenous malformations. J Med Phys 2018;43:214-20.

Access this article online

Quick Response Code:

Website:
www.jmp.org.in

DOI:
10.4103/jmp.JMP_25_18

are scores which quantify the plan information provided by dose distribution and DVH. The metrics can compare different plans and help in the choice of treatment but are often difficult to interpret. The clinical value of the plan quality metrics has to be evaluated before their use as a complementary tool.[5]

In an ideal SRS plan, the whole target should receive at least the prescription dose and the dose at the target boundary should immediately drop to zero.[7]

In our institute, all SRS plans are evaluated by visual inspection of dose distribution and DVH. Only one plan quality metric namely, the conformity index as defined by the Radiation Therapy Oncology Group (CI$_{RTOG}$), has been used for reporting. The aim of this study is to retrospectively evaluate some of the metrics for already executed treatment plans and ascertain their worth for routine plan evaluation. There have been several studies conducted in other countries, but no Indian data is available.

MATERIALS AND METHODS

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

RTOG
The Radiation Therapy Oncology Group (RTOG) was the first to propose the concept of conformity index in their guidelines.[8] They proposed the following three widely used indices.

a. Conformity Index (CI$_{RTOG}$)

$$CI_{RTOG} = \frac{V_{RI}}{TV} \qquad (1)$$

where V$_{RI}$ is the volume of the prescription isodose and TV is the target volume. CI$_{RTOG}$ has an ideal value of 1. If the value is >1, then it indicates over-treatment (irradiated volume is greater than target volume) and if it is <1 it indicates under-treatment (target volume is only partially irradiated).[8]

b. Quality of Coverage (Q$_{RTOG}$)

$$Q_{RTOG} = \frac{I_{min}}{RI} \qquad (2)$$

where I$_{min}$ is the minimum dose in the target and RI is the prescription dose.[8]

c. Homogeneity Index (HI$_{RTOG}$)

$$HI_{RTOG} = \frac{I_{max}}{RI} \qquad (3)$$

where I$_{max}$ is the maximum dose in the target and RI is the prescription dose.[8]

The uniformity of dose distribution within the target volume is characterized by the homogeneity index.[9]

Table 1 shows the range of values for which the above indices agree with RTOG guidelines or show minor or major deviations.

Alternative indices
CI$_{RTOG}$ gives greater importance to target coverage rather than to adjacent normal tissue avoidance.[7] This index is criticized for not taking into account the location and shape of the prescription isodose volume. It can still give a perfect score of 1 even if the target volume and prescription isodose volume partially overlap or do not overlap at all, thus irradiating a significant amount of normal tissue.[6,7] It is illustrated in Figure 1. This could lead to the selection of an inferior plan when comparing two potential plans.[6]

Many alternative indices have been proposed in literature to eliminate the false scores of CI$_{RTOG}$.[5] Two other indices, Lomax conformity index (CI$_{Lomax}$) and Paddick's conformity index (CI$_{Paddick}$) proposed by Lomax and Paddick have also been selected and analyzed in the present study as alternate options.

Lomax conformity index (CI$_{Lomax}$)
It was proposed by Lomax and Schieb in 2003.[7]

$$CI_{Lomax} = \frac{TV_{PIV}}{TV} \qquad (4)$$

where TV$_{PIV}$ is the target volume covered by the prescription dose, and TV is the target volume.[7] The CI$_{Lomax}$ shows the proportion of the target volume that receives at least the prescription dose. Its value ranges from 0 to an optimum value of 1.[7] If CI$_{Lomax}$ value is >0.5, then it is equivalent to a CI$_{RTOG}$ value between 1 and 2. The planning aim should be to achieve a CI$_{Lomax}$ value of 0.6 or more.[5,7] However, the CI$_{Lomax}$ can give a conformity index of unity even for whole brain irradiation.[6]

Table 1: Values of Radiation Therapy Oncology Group indices

CI$_{RTOG}$	Q$_{RTOG}$	HI$_{RTOG}$	Agreement to RTOG guidelines
1.0-2.0	≥0.9	≤2.0	As per guidelines
2.0-2.5 and 0.9-1.0	≥0.8 and <0.9	>2.0 and ≤2.5	Minor deviations
>2.5 or <0.9	<0.8	>2.5	Major deviations

RTOG: Radiation Therapy Oncology Group, CI$_{RTOG}$: Conformity index RTOG, Q$_{RTOG}$: Quality of coverage RTOG, HI$_{RTOG}$: Homogeneity index RTOG
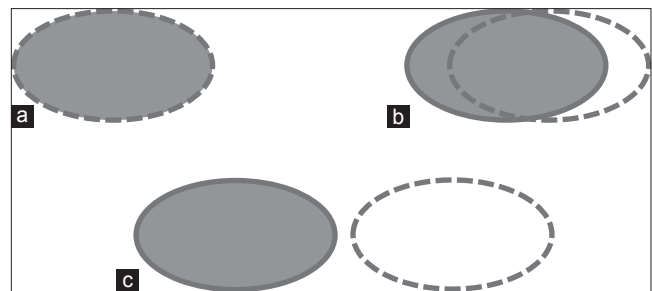

Figure 1: Intersection of the target and prescription isodose (dotted line) (a) Perfect overlap, (b) Partial overlap, and (c) No overlap. The volume of the target and the prescription isodose is the same in all the three scenarios and hence yields a perfect Radiation Therapy Oncology Group Conformity Index (CI$_{RTOG}$)

Paddick's conformity index (CI$_{Paddick}$)

As an alternative to CI$_{Lomax}$, CI$_{Paddick}$ has been proposed that takes into account the normal tissue that receives the prescription dose.[6] CI$_{Paddick}$ is the same as the conformation number (CN) proposed earlier by van't Riet *et al*. CN was initially tested for conformal radiotherapy and ^{125}I brachytherapy implant for carcinoma of the prostate.[10] Paddick applied the same formula to SRS plans.[6]

CI$_{Paddick}$ is the product of the under-treatment ratio (UTR) and the over-treatment ratio (OTR).

$$UTR = \frac{TV_{PIV}}{TV} \tag{5}$$

It is the same as CI$_{Lomax}$

The OTR is the proportion of V$_{RI}$ inside the target

$$OTR = \frac{TV_{PIV}}{V_{RI}} \tag{6}$$

These two ratios when combined give

$$CI_{Paddick} = \frac{TV_{PIV}{}^2}{TV \times V_{RI}} \tag{7}$$

Equation (7) is also recommended by ICRU-91 for reporting as conformity index in SRS/stereotactic radiotherapy (SRS/SRT) plans.[9]

A conformal plan will have a CN >0.6. There are no situations where CN will give a "false perfect" score.[7,10] CI$_{Paddick}$, UTR, and OTR have an ideal value of 1 and plan quality decreases with decreasing index value. This index combines the information provided by RTOG and Lomax into a single index.[6] CI$_{Paddick}$ is independent of volume and will give a score of unity only for a perfectly conformal plan.[6] Paddick has not defined an ideal value for the index. This index does not give any information on whether the lack of conformity is due to under-treatment or over-treatment. To understand the lack of conformity each ratio has to be considered separately.[6]

CI$_{Paddick}$ can be written in terms of CI$_{RTOG}$

$$CI_{Paddick} = \frac{TV_{PIV}{}^2}{TV^2 \times CI_{RTOG}} \tag{8}$$

From equation (8) it can be seen that CI$_{Paddick}$ and CI$_{RTOG}$ are inversely related.

This also gives rise to yet another parameter called the Geometric Overlap Ratio that accounts for the overlap between the target and treated volumes. The square root of this ratio gives CI$_{Lomax}$.

$$\text{Geometric Overlap Ratio (GOR)} = \frac{TV_{PIV}{}^2}{TV^2} \tag{9}$$

Gradient indices

Conformity indices quantify how well the dose distribution conforms to the shape and size of the target volume. The dose-fall off outside the target volume is also very important in SRS as a measure of plan quality, especially as a predictor of complications.[11] Significant regions of normal tissue outside the target are irradiated by the lower isodoses and are responsible for most of the normal tissue complications.[12]

Gradient indices have been proposed to compare treatment plans of equal conformity. One of the factors that is characteristic of SRS is the steep dose gradient outside the target. This is very important when the target is in proximity to critical structures. Hence, it is important to quantify this variable and use it to compare competing plans or treatment modalities.[11]

Paddick's gradient index (GI$_{Paddick}$)

It is defined as the ratio of the volume of half the prescription dose to the volume of the prescription dose.[11]

$$GI_{Paddick} = \frac{V_{50\%}}{V_{100\%}} \tag{10}$$

Equation 10 is also recommended by ICRU-91 for reporting as gradient index in SRS/SRT plans.[9]

Equivalent fall-off distance (EFOD)

Equivalent fall-off distance (EFOD) is defined as the equivalent radial distance between two isodose lines. This is a useful index for comparing the dose fall-off-rate of SRS plans.[13] To derive this, treatment volume ratio (TVR) needs to be defined.[14]

$$TVR = \frac{TV}{V_{RI}} \tag{11}$$

where TV is the target volume and V$_{RI}$ is the irradiated volume. This ratio gives information on how much of the normal tissue receives the prescription dose.[14]

TVR is used for the calculation of EFOD.

$$EFOD = (\sqrt[3]{TVR_1} - \sqrt[3]{TVR_2}) \times R \tag{12}$$

where TVR$_1$ and TVR$_2$ are the TVRs for dose values under consideration and R is the equivalent radius of the target volume.

In this study, the EFOD was calculated for the dose fall-off from 100% to 50%. Hence, TVR$_1$ and TVR$_2$ are the TVRs for 100% and 50% isodose, respectively.

Treatment plans

We implemented SRS treatment on a Varian© Clinac-iX© linear accelerator. A micro multileaf collimator (MLC) m3 by Brainlab© is used to shape the field apertures. The MLC is fitted as an add-on below the jaws before execution. The m^3 MLC has 26 pairs of leaves. The central 14 pairs, the middle 6 pairs, and outer 6 pairs of leaves each have a width of 3.0 mm, 4.5 mm, and 5.5 mm at the isocenter, respectively.

Spherical target plans

Spherical targets were generated to study the influence of dose calculation grid size on plan quality metrics. Spherical volumes of 0.3 cm^3, 0.6 cm^3, 1 cm^3, 2 cm^3, 3 cm^3, 4 cm^3, 5 cm^3, 8 cm^3, 10 cm^3, 20 cm^3, 25 cm^3, and 30 cm^3 were created

in Brainlab© iPlan© v4.5.4 treatment planning system on computed tomography (CT) data of a selected patient.

A standard static conformal plan with 11 treatment beams was made into a template. This template was used to generate plans for the 12 spherical targets. A uniform MLC margin of 2 mm was used for all targets. The planning aim was to deliver 20 Gy to at least 99.5% of the target volume. For each of the 12 plans, data were obtained for dose calculation grid size of 2 mm and 1 mm. The differences between these two sets of data were compared using paired *t*-test at 5% level of significance.

Patient plans

We have treated 193 patients with SRS out of which 133 patients were treated for arteriovenous malformations (AVMs) since 2012. Since 69% of SRS treatments were given to AVM patients, a sample of patients was chosen consecutively from this cohort for the study.

Sixty clinically accepted and already executed SRS/SRT conformal plans (SRS-56 plans and SRT-4 plans) for the treatment of AVMs were selected for this study to assess the clinical usefulness of various plan quality metrics. The target volume distribution for the 60 patients is shown in Table 2. The target volumes ranged from 0.13 cm^3 to 26.66 cm^3 with a mean volume of 2.94 cm^3.

A common template was not used for all plans. The gantry, couch, and collimator angles were chosen individually for each patient accordingly based on (i) the location of the target, (ii) the avoidance of organs at risk in the beam pathway, and (iii) avoidance of collision between gantry, couch, and collimator. The number of beams ranged from 8 to 15, and the prescription dose ranged from 13 Gy to 30 Gy for this patient cohort.

RESULTS AND DISCUSSION

Influence of dose calculation grid size on plan quality metrics

CI_{RTOG} ($P = 0.111$), Q_{RTOG} ($P = 0.122$), HI_{RTOG} ($P = 0.099$), CI_{Lomax} ($P = 0.579$), $CI_{Paddick}$ ($P = 0.298$), UTR ($P = 0.579$), OTR ($P = 0.150$), $GI_{Paddick}$ ($P = 0.117$), and EFOD ($P = 0.106$) did not show any statistically significant difference for dose calculation grid sizes of 2 mm and 1 mm for the 12 spherical target plans. This shows that plan quality metrics are independent of the calculation grid sizes ≤2 mm and hence not considered in the analysis. We routinely use a grid size of 2 mm for SRS dose calculations.

Analysis of Radiation Therapy Oncology Group indices
RTOG conformity index (CI$_{RTOG}$)

The scatter plot of CI_{RTOG} versus target volume is shown in Figure 2. In our study, CI_{RTOG} of 95% of the plans were as per RTOG guidelines, 1.7% showed minor deviations and 3.3% showed major deviations. The three plans that had shown minor and major deviations had target volumes <1 cm^3. This happens probably because for smaller targets, a small change in absolute volume might translate into a large relative change. Similar results were obtained in other studies also.[7,15] For target volumes <1 cm^3, if the prescription isodose extends

Table 2: Target volume distribution of 60 patients

AVM size (cm³)	*n*
<1	13
1-≤2	19
2-≤3	10
3-≤4	8
4-≤5	5
5-≤10	2
>10	3
Total	60

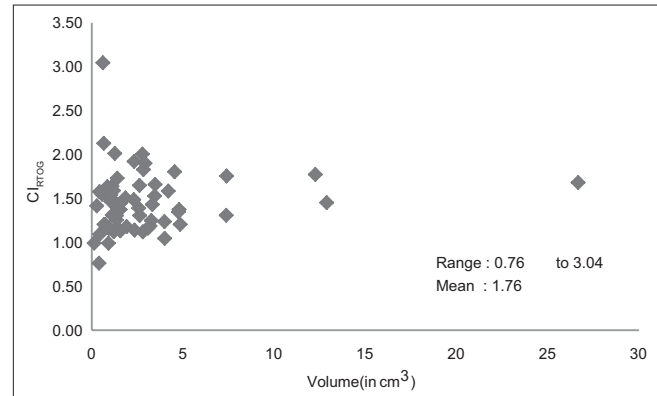AVM: Arteriovenous malformation

Figure 2: Scatter plot of RTOG Conformity Index (CI$_{RTOG}$) versus target volume

beyond the target even by 1 mm, it will result in a significant increase of volume treated to the prescription dose.[7]

There were 13 targets in this study with volumes <1 cm^3. However, only 3 cases out of 13 showed deviations from RTOG guidelines. These plans were analyzed to ascertain the cause of the deviation. The shape of the targets is shown in the relevant sectional images.

The one plan with minor deviation ($CI_{RTOG} = 2.01$, volume = 0.656 cm^3) had an irregular C-shaped target volume as shown in Figure 3a. Of the two plans with major deviation, the one with $CI_{RTOG} = 3.01$ and volume = 0.609 cm^3 also had an elongated C-shaped target which might be the reason for poor conformity as shown in Figure 3b. The CI_{RTOG} for both these plans indicates over-treatment. The avoidance of prescription dose within the C-shaped structure is not possible with conformal plans. A better conformity is probably possible with intensity modulated SRS (IMSRS) plans.

The second plan with major deviation ($CI_{RTOG} = 0.8$, volume = 0.394 cm^3) had a roughly spherical volume as shown in Figure 3c. The CI_{RTOG} indicates under-treatment. On further analysis, it was found that the AVM initially contoured had a very small volume of 0.161 cm^3. A 1 mm PTV margin was given due to the small volume. Although the original target is well covered, full coverage of the enlarged volume was not attempted. Hence, a poor CI_{RTOG} index was obtained.

Nakamura *et al*. found a direct correlation between conformity and toxicity. Targets <1 cm^3 showed poor conformity, but no complications occurred. For larger lesions, it was easier to
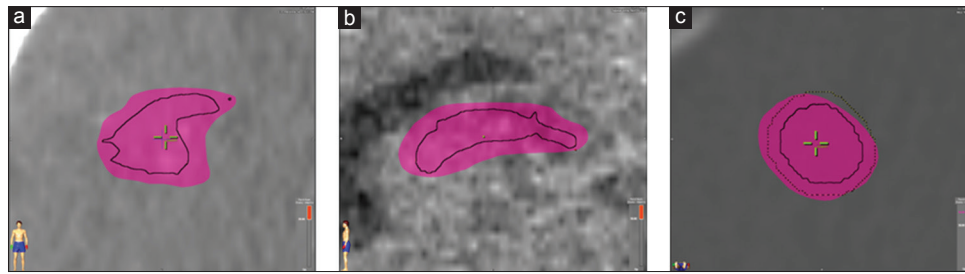
Figure 3: Dose distribution superimposed on (a) coronal CT image of plan with CI_{RTOG}=2.01 (Volume=0.656 cm³), (b) sagittal CT image of plan with CI_{RTOG}=3.04 (Volume=0.609 cm³) and (c) axial CT image of plan with CI_{RTOG}=0.80 (Volume=0.394 cm³)

generate a conformal plan, but toxicities were more because of the greater irradiated volume.[11,16]

RTOG Quality of Coverage(Q_{RTOG})

Figure 4 shows the scatter plot of Q versus target volume. The quality of coverage for 91.7% of the plans was as per RTOG guidelines, 5% of the plans showed minor deviations, and 3.3% of the plans showed major deviations. If the Q_{RTOG} is used together with CI_{RTOG}, then any geometric mismatch if present will be apparent.[7]

Quality of coverage is an indication of the minimum dose in the target. When the minimum dose is closer to the prescribed dose, then this index will be close to unity.

The five plans which showed deviations from guidelines were analyzed. It was found that all five plans had irregular targets. Small parts of target protrude from the main body resulting in under-dosage, and hence a lower value of Q was seen. One such example is shown in Figure 5. Under-dosage was observed during a visual inspection of isodose and probably ignored because it was not clinically relevant.

RTOG homogeneity index (HI_{RTOG})

Figure 6 shows the scatter plot of HI_{RTOG} versus target volume. The homogeneity index was as per guidelines for all the plans. HI_{RTOG} is important in the treatment of AVMs since the risk of complications is related to the dose inhomogeneity within the target.[13,17] Hence, it is better to report HI_{RTOG}, although for all our plans, we have obtained a value as per guidelines. No other index will be able to provide an indication of the maximum dose within the target.

Analysis of Lomax conformity index(CI_{Lomax})

Figure 7 shows the scatter plot of CI_{Lomax} versus target volume. For 98.3% of the cases, the CI_{Lomax} had a value >0.8. For the one case with <0.8, the CI_{RTOG} (CI_{RTOG} = 0.8) was also not as per guidelines. Similar results were obtained in the study by Stanley *et al.*[15] The CI_{Lomax} worsens for targets <1 cm³.[7] The volume of a target for which the CI_{Lomax} was not as per guidelines was 0.39 cm³.

The target volumes and prescription isodose volumes geometrically overlap in routine clinical treatment planning. The GOR for 83.3% of the cases is >0.95. In a similar study by Julia Stanley *et al.*, 89% of the 160 targets had a GOR >0.95.[15] Hence, if a dose distribution is available for visual inspection, the information provided by this ratio is not critical for plan evaluation.

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

Figure 8 shows the scatter plot of $CI_{Paddick}$ versus target volume. An ideal value for Paddick's index has not been defined. In our study, 70% of the plans had a $CI_{Paddick}$ value >0.6 and 30% of the plans had a $CI_{Paddick}$ value <0.6.

In studies by Stanley *et al.* and Wu *et al.*, this index worsened for targets <1 cm³.[15,18] However, in our study, the average Paddick's index 0.67, did not differ with target volume. The OTR ranged from 0.33 to 0.98 with a mean value of 0.69 and the UTR ranged from 0.75 to 1.00 with a mean value of 0.97. For the 60 cases studied, $CI_{Paddick}$ decreased due to over-dosage of the target and not due to under-dosage. A plan with a higher $CI_{Paddick}$ need not be a suitable plan, and hence, OTR and UTR must be analyzed separately for plan evaluation.[7]

Analysis of gradient indices

Paddick's gradient index ($GI_{Paddick}$)

Figure 9 shows the scatter plot of $GI_{Paddick}$ versus target volume. In the paper by Paddick, it ranged from 2.4 to 3.3 with a mean value of 2.83 for 58 targets treated using Gamma Knife.[11] In the study by Paddick *et al.*, target volumes <0.2 cm³ were excluded. Conformity is reduced for such small volumes because of the inherent spillage of radiation dose in these treatments.[11] If $GI_{Paddick}$ = 17.45 (volume = 0.134 cm³) is considered as an outlier, then it varies from 2.46 to 8.46 with a mean value of 4.45.

In our study, 78.3% of the cases had a $GI_{Paddick}$ between 2.0 and 5.0, 20% had $GI_{Paddick}$ between 5.0 and 10.0, and 1.7% had $GI_{Paddick}$ >10.0.

Equivalent fall-off distance (EFOD)

Figure 10 shows the scatter plot of EFOD versus target volume. In this study, it was seen that for 13.3% of the cases, the EFOD ranged from 1.0 mm to 2.0 mm with an average target volume of 0.6 cm³. For 58.3% of the cases, the EFOD was between 2.0 mm and 3.0 mm with an average target volume of 1.89 cm³. For 25% of the plans, the EFOD ranged between 3.0 mm to 4.0 mm and the average target volume for these plans was 4.39 cm³. For 3.3% of the cases, the EFOD was >4.0 mm and for these two cases out of sixty; the target volumes were high with an average of 19.77 cm³. Hence, it can be concluded that the EFOD increases linearly with the target volume with an R value of 0.81. A rapid dose fall off is seen for smaller targets.

The EFOD was studied for the 12 spherical targets. It was found that EFOD increases linearly with target volume (R = 0.94 for
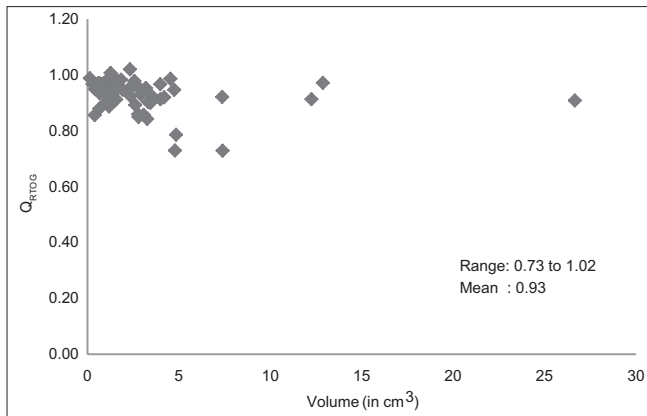
Figure 4: Scatter plot of RTOG Quality of Coverage (Q_{RTOG}) versus target volume
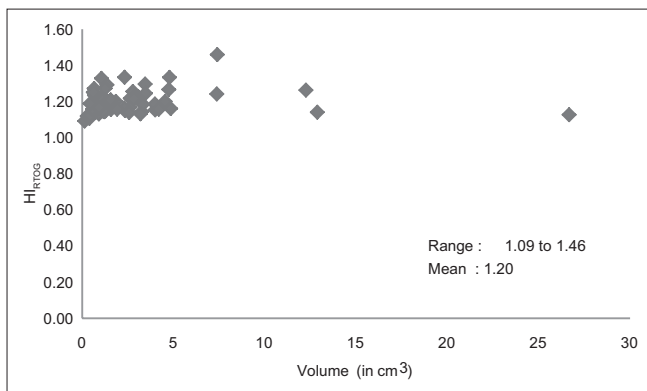

Figure 6: Scatter plot of RTOG Homogeneity Index (HI_{RTOG}) versus target volume
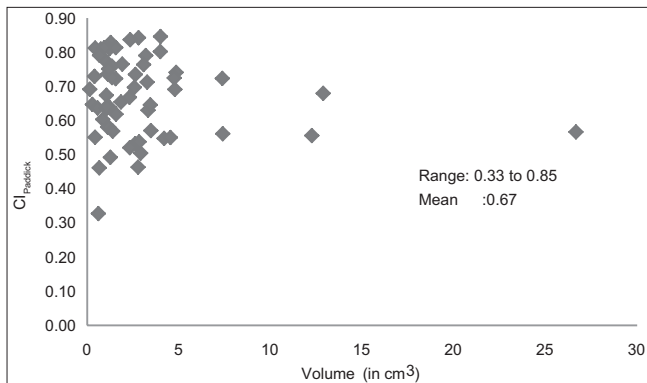

Figure 8: Scatter plot of Paddick's Conformity Index ($CI_{Paddick}$) versus target volume

Figure 5: Dose distribution superimposed on coronal CT images of a plan that shows major deviation from RTOG guidelines ($Q_{RTOG} = 0.70$, Volume = 4.874 cm^3). The target is irregularly shaped and the protrusions do not receive the prescribed dose which has resulted in a lower value of Q_{RTOG}

Figure 7: Scatter plot of Lomax Conformity Index (CI_{Lomax}) versus target volume

Figure 9: Scatter plot of Paddick's Gradient Index ($GI_{Paddick}$) versus target volume

spherical targets and R = 0.81 for patient data) as shown in Figure 11. A linear fit equation was obtained for spherical targets.

$$EFOD = 0.08\,TV + 2.97 \tag{13}$$

where EFOD is the equivalent fall-off distance for 100% dose to 50% dose in mm and TV is the target volume in cm^3.

Equation 13 was applied to the 60 patient targets under study. The difference between the EFOD calculated from the TVR ratios and the linear fit ranged from −1.6
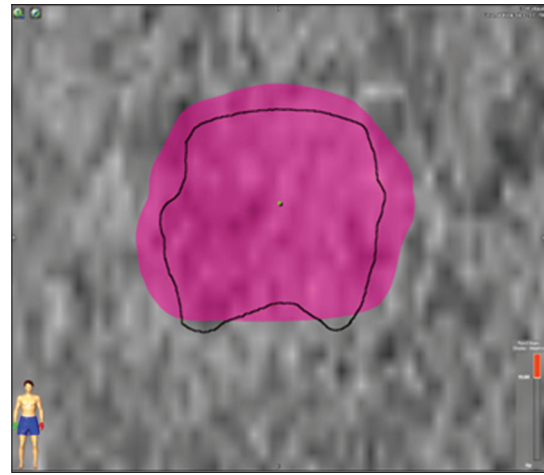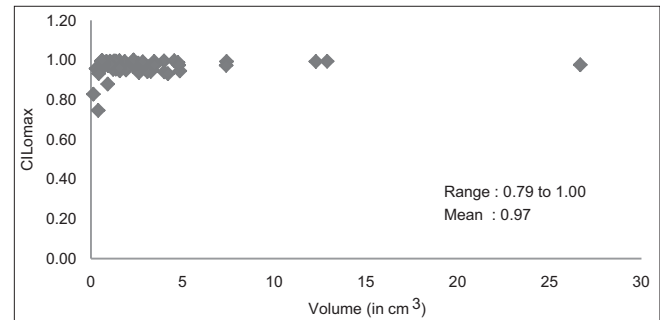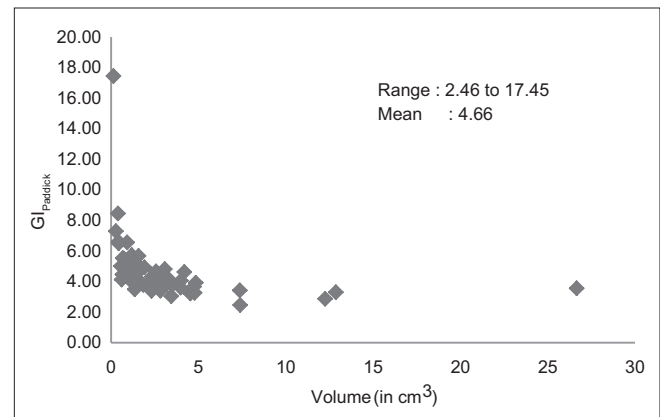
to 0.4 mm with a mean of −0.5 mm. Hence, equation 13 although not accurate, can be used as an approximation of EFOD of 100% to 50% isodose in routine clinical practice and matched with the EFOD calculated from TVR parameters.
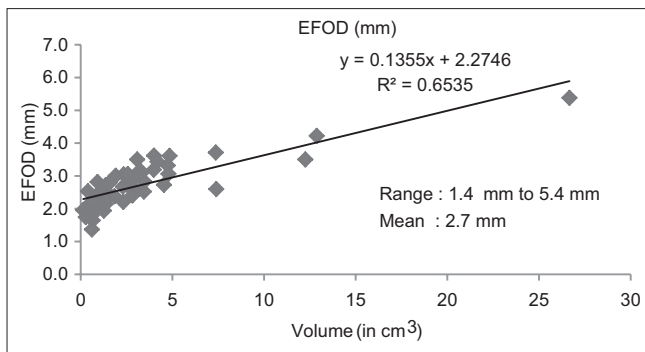
Figure 10: Scatter plot of equivalent fall-off distance (EFOD) versus target volume
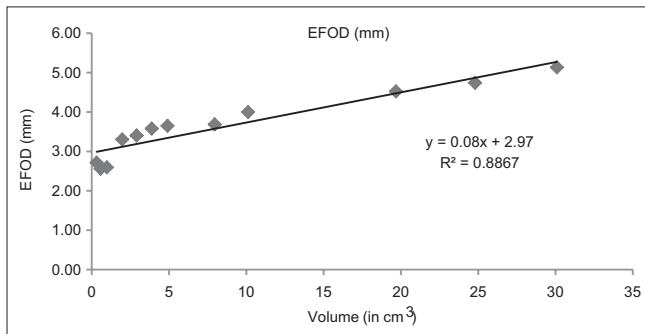

Figure 11: Scatter plot of equivalent fall-off distance (EFOD) versus volume for spherical targets

Conclusions

A dose calculation grid size of 2 mm is sufficient for routine clinical planning since a finer resolution does not alter the plan quality metrics.

The analysis shows that it is not necessary to calculate alternative indices such as CI_{Lomax} and $CI_{Paddick}$ for routine plan evaluation. The information these indices convey can be obtained from an available dose distribution and the RTOG indices. CI_{Lomax} was introduced because of the possibility of the target and prescription isodose volumes not overlapping. However, if a dose distribution superimposed on patient image-data are available, this situation does not arise in the clinical scenario. If the CI_{RTOG} is greater than 1, it indicates over-treatment, and if it is <1, it indicates under-treatment which makes UTR and OTR redundant.

EFOD is suggested as a gradient parameter for routine plan evaluation. It is easier to interpret this index because it has a physical dimension when compared to $GI_{Paddick}$.

Alternative plan quality metrics such as the $CI_{Paddick}$, CI_{Lomax}, and $GI_{Paddick}$ will be useful for comparing different techniques such as conformal SRS, IMSRS, dynamic arcs or for comparing dose calculation algorithms.

Combined with clinical expertise, for routine plan evaluation CI_{RTOG}, Q_{RTOG}, $HI_{RTOG,}$ and EFOD are sufficient, if dose distribution and DVH are available.

Conflicts of interest

There are no conflicts of interest.

References

1. Khan FM. The Physics of Radiation Therapy. 4th ed. Philadelphia: Lippincott Williams & Wilkins. 2010.
2. Lunsford LD. Dose fractionated gamma knife radiosurgery for large arteriovenous malformations: A word of caution. Neurol India 2017;65:699-700.
3. Podgorsak EB. Special procedures and techniques in radiotherapy In: Radiation Oncology Physics: A Handbook for Teachers and Students. Vienna: International Atomic Energy Agency; 2005. p. 505-16.
4. Chen GT. Dose volume histograms in treatment planning. Int J Radiat Oncol Biol Phys 1988;14:1319-20.
5. Feuvret L, Noël G, Mazeron JJ, Bey P. Conformity index: A review. Int J Radiat Oncol Biol Phys 2006;64:333-42.
6. Paddick I. A simple scoring ratio to index the conformity of radiosurgical treatment plans. Technical note. J Neurosurg 2000;93 Suppl 3:219-22.
7. Lomax NJ, Scheib SG. Quantifying the degree of conformity in radiosurgery treatment planning. Int J Radiat Oncol Biol Phys 2003;55:1409-19.
8. Shaw E, Kline R, Gillin M, Souhami L, Hirschfeld A, Dinapoli R, *et al.* Radiation therapy oncology group: Radiosurgery quality assurance guidelines. Int J Radiat Oncol Biol Phys 1993;27:1231-9.
9. Seuntjens S, Lartigau E, Cora S, Ding GX, Goetsch S, Nuyttens J, *et al.* ICRU report 91. Prescribing, recording, and reporting of stereotactic treatments with small photon beams. J Int Comm Radiat Units 2014;14:101-9.
10. van't Riet A, Mak AC, Moerland MA, Elders LH, van der Zee W. A conformation number to quantify the degree of conformality in brachytherapy and external beam irradiation: Application to the prostate. Int J Radiat Oncol Biol Phys 1997;37:731-6.
11. Paddick I, Lippitz B. A simple dose gradient measurement tool to complement the conformity index. J Neurosurg 2006;105 Suppl:194-201.
12. Flickinger JC, Kondziolka D, Lunsford LD, Kassam A, Phuong LK, Liscak R, *et al.* Development of a model to predict symptomatic postradiosurgery injury for arteriovenous malformation patients. Arteriovenous malformation radiosurgery study group. Int J Radiat Oncol Biol Phys 2000;46:1143-8.
13. Leung LH, Chua DT, Wu PM. A new tool for dose conformity evaluation of radiosurgery treatment plans. Int J Radiat Oncol Biol Phys 1999;45:233-41.
14. Nedzi LA, Kooy HM, Alexander E 3rd, Svensson GK, Loeffler JS. Dynamic field shaping for stereotactic radiosurgery: A modeling study. Int J Radiat Oncol Biol Phys 1993;25:859-69.
15. Stanley J, Breitman K, Dunscombe P, Spencer DP, Lau H. Evaluation of stereotactic radiosurgery conformity indices for 170 target volumes in patients with brain metastases. J Appl Clin Med Phys 2011;12:3449.
16. Nakamura JL, Verhey LJ, Smith V, Petti PL, Lamborn KR, Larson DA, *et al.* Dose conformity of gamma knife radiosurgery and risk factors for complications. Int J Radiat Oncol Biol Phys 2001;51:1313-9.
17. Nedzi LA, Kooy H, Alexander E 3rd, Gelman RS, Loeffler JS. Variables associated with the development of complications from radiosurgery of intracranial tumors. Int J Radiat Oncol Biol Phys 1991;21:591-9.
18. Wu QR, Wessels BW, Einstein DB, Maciunas RJ, Kim EY, Kinsella TJ, *et al.* Quality of coverage: Conformity measures for stereotactic radiosurgery. J Appl Clin Med Phys 2003;4:374-81.