Significance of Dosimetric Parameters in Patients Undergoing Gamma Knife Radiosurgery for Vestibular Schwannoma

Shobha Jayaprakash, Anil M. Pendse, Sudesh Deshpande[1]

Departments of Neurosurgery and Gamma Knife Radiosurgery and [1]Radiation Oncology, P.D. Hinduja Hospital and MRC, Mumbai, Maharashtra, India

Abstract

Vestibular schwannoma (VS) is a benign, encapsulated, and slow-growing tumor of the myelin-forming cells of the 8th cranial nerve. Gamma Knife radiosurgery (GKRS) has become a widely accepted primary treatment modality for small- to medium-sized VSs. In the case of VS, highly conformal, precisely focused radiation is delivered to the acoustic tumor in a single session under the direct supervision of a radiosurgery team. **Aim:** This study aims to determine the significance of Conformity Index and Gradient Index (GI) in patients undergoing GKRS for VS, retrospectively, and re-assess the plans. **Materials and Methods**: A dosimetric study of 112 patients of VS (both operated and nonoperated) treated on Gamma Knife Perfexion unit at our hospital, over a 3-year period, was carried out retrospectively. The patients' mean age at the time of GKRS was 48 years and the mean dose to the tumor margin was 13 Gy. The conformality of the treatment plan was determined by Conformity Index. GI determines fall off dose outside the target. **Results**: The dosimetric parameters such as Conformity Index and GI were calculated using the dose-volume histograms and the volume analysis tools available in the Leksell Gamma Plan using TMR 10 algorithm. The mean Paddick Conformity Index was found to be around 0.80 ± 0.085 and the mean GI was 2.67 ± 0.22. **Conclusions:** The dosimetric parameters can be used to evaluate the dose coverage and conformity and dose fall off outside the target.

Keywords: Conformity index, coverage, gradient index, Leksell Gamma Knife Perfexion, Leksell GammaPlan, vestibular schwannoma

Received on: 22-01-2022 **Review completed on: 16-03-2022** **Accepted on: 06-04-2022** **Published on: 05-08-2022**

Introduction

The Leksell Gamma Knife Perfexion (LGK PFX) (Elekta Instrument AB, Stockholm, Sweden) system was installed in our hospital in August 2018. In LGK PFX, a total of 192 ^{60}Co sources are arranged in a cylindrical configuration in five concentric rings. Three collimators are available for the Perfexion system, 4 mm, 8 mm, and 16 mm, unlike the previous model (4C) which has 4 collimators. The tungsten collimator array is subdivided into eight identical but independent sectors, each containing 72 collimators. This system provides excellent dosimetry performance, unlimited cranial reach, enhanced radiation protection for patient and staff, full automation of the treatment process, and better patient and staff comfort compared to previous models.[1]

Moving from Gamma Knife 4C to the new version, Perfexion, the present study is carried out to calculate the volumetric and dosimetric parameters of vestibular schwannoma (VS) using Leksell Gamma Plan software and compare with the published literature values.

Access this article online

Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_5_22

The two major goals of radiosurgery for VS are long-term tumor control and functional hearing preservation. Treatment planning of VS is challenging due to its shape, proximity to cochlea,[2] brainstem, and other cranial nerve. Conformity Index is a measure of the volume of a radiosurgical dose distribution which conforms to the size and shape of a target volume (TV). Because the success of radiosurgery is related to the extremely conformal irradiation of the target, an accurate method for describing this parameter is important. Furthermore, the dose fall off outside the target is of utmost importance and for this purpose, gradient index (GI) is a powerful tool. This is especially useful when the target is in proximity to critical structures.

Address for correspondence: Dr. Shobha Jayaprakash, Department of Neurosurgery and Gamma Knife Radiosurgery, P.D. Hinduja Hospital and MRC, Veer Savarkar Marg, Mahim, Mumbai - 400 016, Maharashtra, India.
E-mail: shobhajp@hotmail.com

How to cite this article: Jayaprakash S, Pendse AM, Deshpande S. Significance of dosimetric parameters in patients undergoing gamma knife radiosurgery for vestibular schwannoma. J Med Phys 2022;47:206-11.

Conformity index can be defined as an absolute value resulting from the ratio between a fraction of the TV and the volume covered with the certain isodose line. Paddick's new conformity index takes into account the location of the prescription volume with respect to the TV. A perfect plan has a score of 1 and an ideal value for Paddick's conformity index (PCI) conformity could be around 0.85.[3] The new proposed conformity index by Ian Paddick[4] has been used in this study from the available dose-volume histograms (DVHs) of the individualized treatment plan from Leksell GammaPlan.

The GI is defined as the ratio of the volume of half the prescription isodose to the volume of the prescription isodose. For a plan normalized to the 50% isodose line, it is the ratio of the 25% isodose volume to that of the 50% isodose volume.[4] The GI can be used to compare treatment plans of equal conformity.

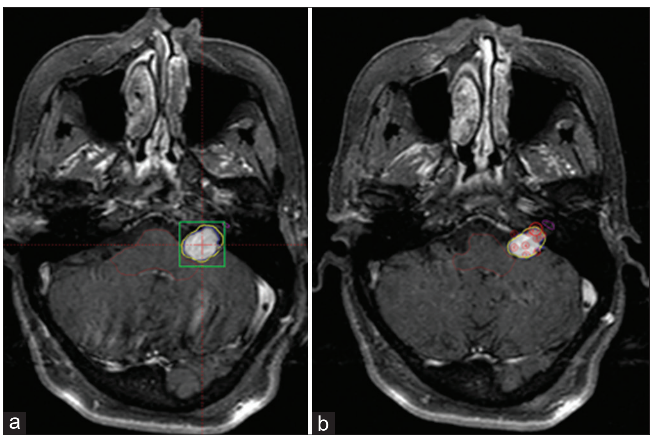

Figure 1: Calculation matrix (a) and isocenters with the 50% prescription isodose line (in yellow)

Materials and Methods

A retrospective study was carried out on 112 patients of VS treated at our hospital between 2018 and 2021 on Leksell Gamma Knife (Elekta Instrument AB, Stockholm, Sweden), Perfexion unit.

On the day of the procedure, an MRI-compatible Leksell stereotactic frame, Model G, Elekta Instruments, was fixed on the patients' head under local anesthesia. High-resolution 1.5 Tesla MRI scans to cover the entire lesion and surrounding critical structures were acquired with a fiducial system attached to the stereotactic frame. The stereotactic images were then transferred to the GammaPlan® dose planning computer. The target and the organs at risk (OAR) were contoured and a conformal plan was obtained. During dose planning, complete coverage of the target with minimum dose to the OAR was given priority.

The individualized treatment plans of all the 112 patients were evaluated from the database of Leksell GammaPlan, Version 10.2.1, and the following dosimetric indices were defined and calculated from all plans on the basis of DVHs: conformity index, GI, and coverage. A comparison of the conformity index and GI parameters and their dependence on the TV was also studied.

The mean age of the patients under study was 48 years (range: 22–75 years). Among these cases, the volumes of target ranged from 0.20 cm^3 to 11.0 cm^3 and the dose range was between 11 and 13 Gy, prescribed to 50% isodose line with a coverage of more than 90%. The prescription dose was selected on the basis of TV, location, and the proximity to critical structures. All the cases were planned with Leksell GammaPlan using TMR 10 algorithm.

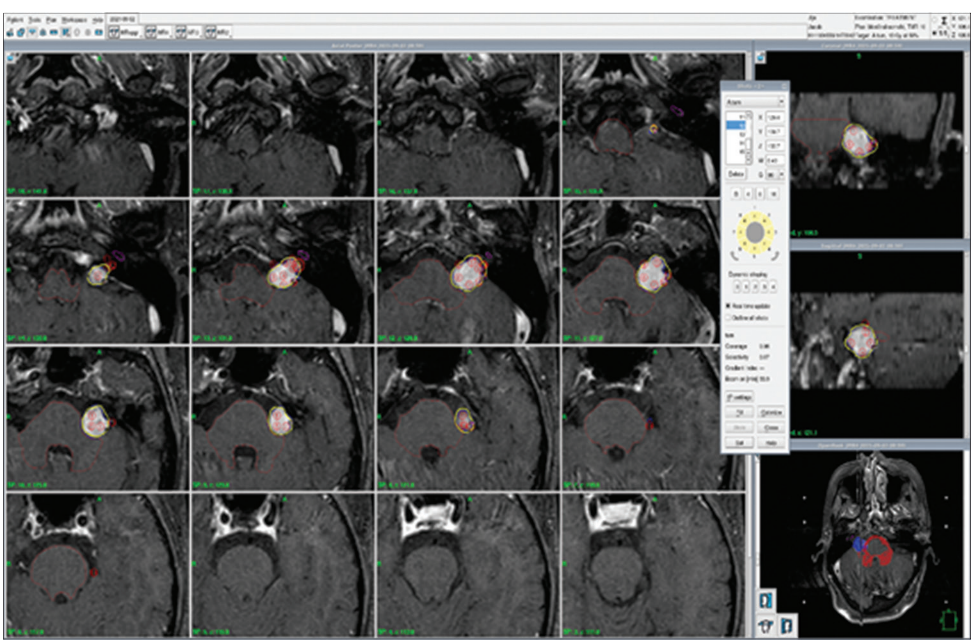

Figure 2: Standard view of the dose plan for vestibular schwannoma showing the distribution of shots

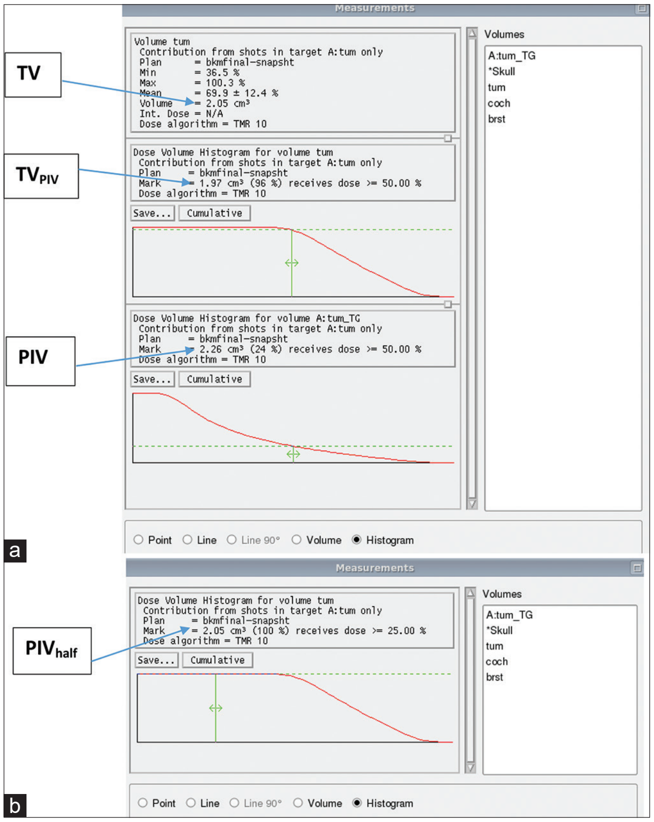

Figure 3: (a) Target Volume & DVH for tumour & PIV (b) DVH showing volume of 25% IDL

In this study, the dosimetric indices were calculated individually for all the patients from the DVH. The Eqs (1-3) represent the calculation of PCI, GI, and coverage, respectively.

The software provides these metric values at the end of the dose calculation.

$$\text{CI Paddick} = \frac{TV_{PIV}}{PIV} \times \frac{TV_{PIV}}{TV} = \frac{TV^2{}_{PIV}}{PIV \times TV} \quad (1)$$

where prescribed isodose volume (PIV) is the isodose volume for the prescription dose, TV is the TV, and TVPIV is the TV receiving the prescription dose.

Paddick's new conformity index[5] takes into account the location of the prescription volume with respect to the TV.

The conformity index used earlier was the ratio of PIV to the volume within the prescribed isodose.

$$\text{Gradient Index} = \frac{PIV_{(half)}}{PIV} \quad (2)$$

Coverage is defined as the TV covered by the *PIV*, i.e.,

$$\text{Coverage} = \frac{TV_{PIV}}{TV} \quad (3)$$

In the LGP, a calculation matrix[6] of sufficient dimension was created for each defined TV [Figure 1a]. The next step was to prescribe the dose using the 50% (IDL) isodose line as the TV dose. The planning was done using the TMR 10 algorithm, wherein heterogeneity correction was not considered. Planning was done by either inverse planning or forward planning or a combination of both. Multiple isocenters were used to cover the TV [Figure 1b]. To prevent radiation spillage into the normal surrounding brain tissue, composite shots with beam blocking were used during treatment planning, especially when the target is very close to OAR.

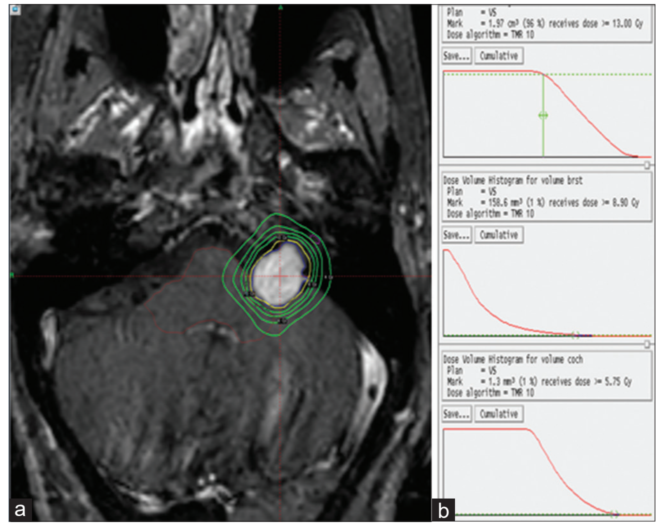

Figure 4: (a) Isodose lines corresponding to 4, 6, 8, 10, and 13 Gy and the DVH. (b) the coverage for 13 Gy prescription dose and the dose received by brainstem and cochlea. DVH: Dose-volume histogram

The standard view of the dose plan showing the axial, coronal, sagittal, and the three-dimensional (3D) view is shown in Figure 2.

Figure 3a and b shows the DVH s and the volume analysis tools from LGP.

The TV, *TVPIV,* and *PIV*, for each treatment plan, were obtained using the DVH. The dosimetric parameters such as coverage (C), GI, and PCI (CIPaddick) were used to evaluate the dose distribution.

DVH is the representation of quantified 3D dose distribution. It quantifies minimum, maximum, and mean dose values delivered to the volume of interest and critical organs. Figure 4 shows the different isodose lines and the DVH in absolute dose.

After prescribing the margin dose, the fall off on cochlea and brainstem were checked to keep them below tolerance level. In cases where hearing preservation is required, the dose to cochlea was kept below 6-8 Gy. The dose to the brainstem was kept well below 12 Gy. Depending on the proximity of the brainstem and cochlea to the target, the dose to the target was adjusted. Hybrid shots were used when the target was close to OAR along with sector blocking.[7]

The treatment plan parameters and metrics of the present study are evaluated and tabulated in Table 1.

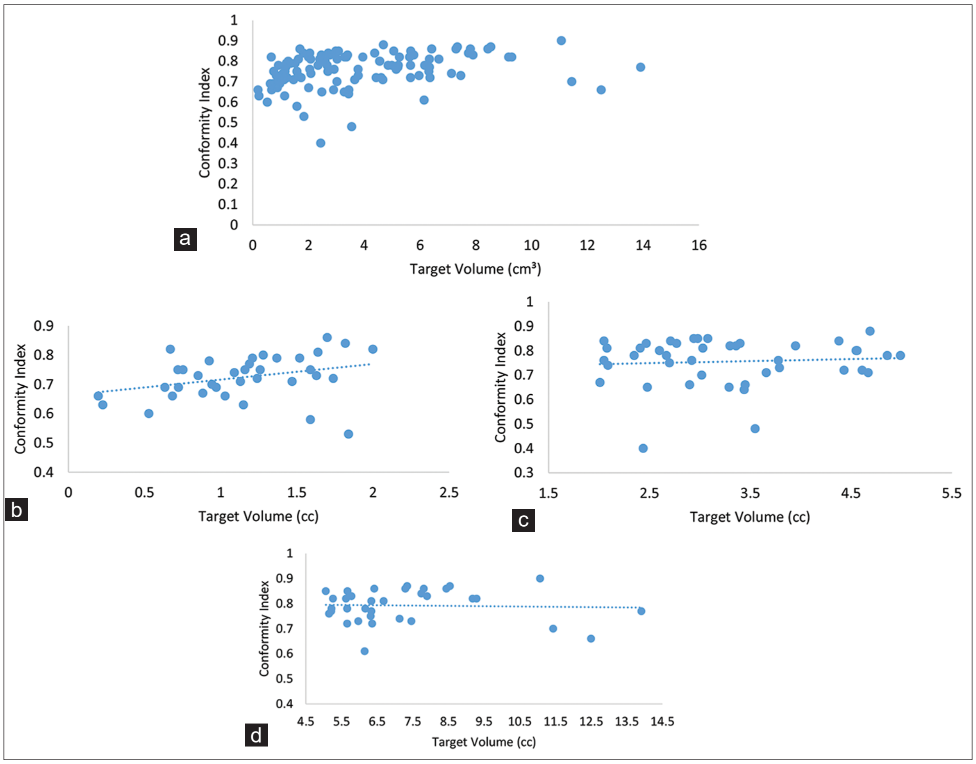

Figure 5: (a) Relation between Conformity Index and target volume. (b) Small volume upto 2cc. (c) Medium volume (2 – 5 cc). (d) Large volume (> 5cc)

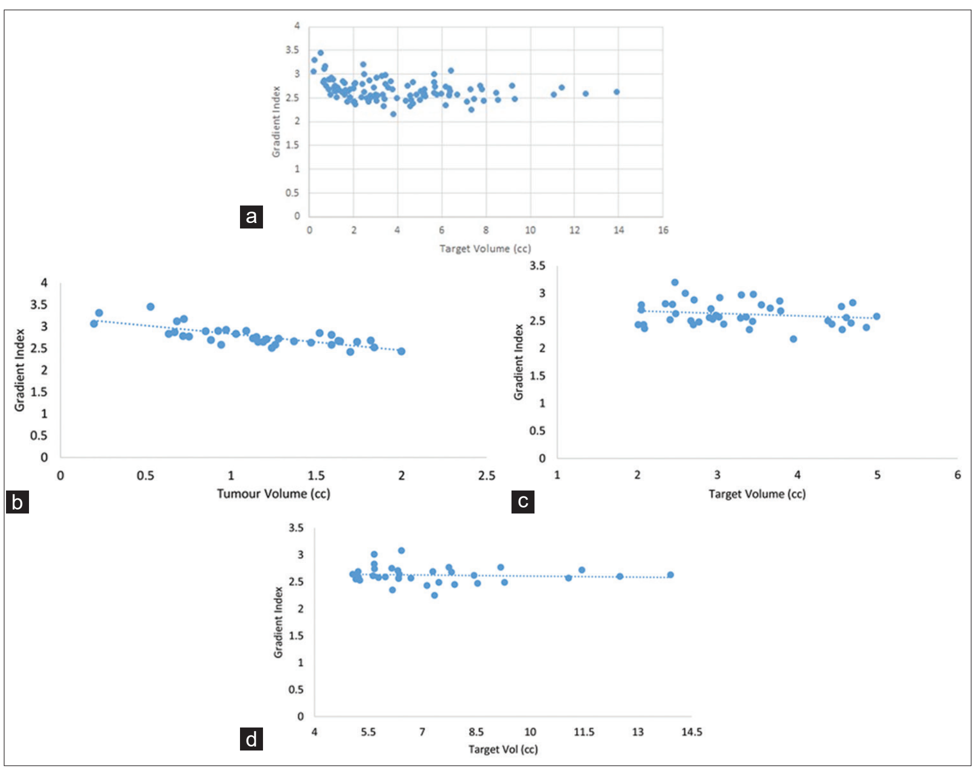

Figure 6: (a) Gradient index versus target volume. (b) Small volume (upto 2cc). (c) Medium volume (2 – 5cc). (d) Large volume (> 5cc)

Results

In the study of 112 dose plans of VS, treated over a 3-year period, on Gamma Knife Perfexion unit, the mean GI was 2.67 (median 2.67, range 2.17–3.45). Nine treatment plans had GI greater than 3.00. These plans were again analyzed and found that the isocenters were placed on the edge of the target

Table 1: Treatment plan parameters - vestibular schwannoma

Factor	Value
Number of cohorts	112
Age (years), mean (range)	48 (22-75)
Male: Female	55:57
Prescription isodose (%)	50
Dose (Gy)	11-13
TV (cc)	
Mean	5.6
Range	0.2-11
SD	±2.8
Isocenters, mean (range)	18 (5-47)
Coverage	
Mean	0.95
Range	0.89–0.99
SD	±0.02
Selectivity	
Mean	0.79
Range	0.42-0.93
SD	±0.09
GI	
Mean	2.67
Range	2.17-3.45
SD	±0.22
PCI	
Mean	0.80
Range	0.69-0.90
SD	±0.085

SD: Standard deviation, PCI: Paddick Conformity Index, GI: Gradient Index, TV: Target volume

and hence the GI was higher. The results also showed that GI is inversely proportional to the target size for smaller volumes.

The average conformity index in all these plans was in the range of 1.10–1.30. In the present study, the new PCI was calculated to evaluate the treatment plans. The mean Paddick CI was found to be 0.80.

Ten plans with lower Paddick CI values (0.40–0.67) were excluded from the study because most of these cases had two or more targets included in the same dose matrix. Hence, the volume could not be extracted for each target separately. The lower CI values may also be attributed to the irregular shape of the target.

The data as shown in Figures 5 and 6 were further analyzed in terms of "small," "medium," and "large" targets.

For very small targets (<1 cm^3) and those having irregular target contour, it may be difficult to cover the target using the spherical LGK shots. For target with volumes smaller than about 2 cm^3, the conformity parameter is seen to be dependent on the TV. As shown in Figure 5a, the conformity index is seen to decrease with target size for TVs less than about 2 cm^3. On the other hand, for TVs greater than 2 cm^3, the conformity index is independent of the target size [Figure 5b and c].

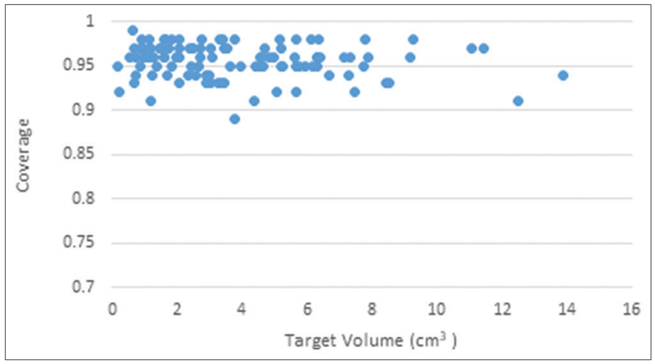

Figure 7: Coverage versus target volume

The GI quantifies dose fall off outside the target. Hence, the dose spread into the normal brain tissue needs to the evaluated in order to reduce the side effects and complications associated with it. A steeper dose gradient gives a more favorable GI. From our retrospective review [Table 1], the average GI was found to be 2.67 with a range of 2.17–3.45.

Lower GI's (<3.0) reflects a sharp dose gradient and properly placed isocenters [Figure 6a-c]. GI is dependent on the target shape and size and also influences the dose received by the healthy brain tissue.

Target coverage was another dosimetric parameter that was studied. As shown in Figure 7, the target coverage is seen to be independent of TV, but it is dependent on the target location. If the target is close to the critical structures such as brainstem or cochlea, then the sparing of the critical structures may lead to lower target coverage. In the present study, the coverage was around 95% with a range of 89% to 99% (standard deviation [SD] ± 0.02) for all the evaluated plans.

Discussion

In LGK PFX, the setup and treatment of patients is much more efficient than its predecessors,[8] because it is a fully automated system. The system also provides more options to generate plan with high dosimetric conformity. The plans can be re-assessed, and re-planning can be done to reduce the dose fall off, thereby minimizing OAR dose, if it is found to be above the tolerance level.

For targets in proximity to critical structures, it is often not possible to treat such tumors to a curative dose due to its sensitivity to radiation. In such cases, the target dose needs to be reduced in order to restrict the dose to the OAR below their tolerance dose. The judicious use of hybrid shots for targets close to the critical structures is the best way to achieve conformal treatments. The plan indices can also be important predictors of hearing outcomes.[9]

The dosimetric parameters such as PCI and GI are good indicators of how well the dose distribution conforms to the target shape and size. Any variation from the stipulated value indicates that the target is either under dosed or over dosed.

Conclusions

PCI of 0.80 was found to give a good target coverage (95%). A GI of <3 reflected a steeper dose gradient and well-placed isocenters. Further, these need to be correlated with clinical results.

Thus, the conformity index and GI can be objective tools for the evaluation of plan quality. Lower complications along with high tumor control rate makes Gamma Knife radiosurgery a good option for patients diagnosed with VS.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Novotn’y J. Jr. Leksell Gamma Knife- Past, Present and Future. Clinician and Technology, 2012;42.
2. Timmer FC, Hanssens PE, Van Haren AE, Mulder JJ, Cremers CW, Beynon AJ, *et al.* Gamma knife radiosurgery for vestibular schwannomas: Results of hearing preservation in relation to the cochlear radiation dose. Laryngoscope 2009;119:1076-81.
3. Torrens M, Chung C, Chung HT, Hanssens P, Jaffray D, Kemeny A, *et al.* Standardization of terminology in stereotactic radiosurgery: Report from the Standardization Committee of the International Leksell Gamma Knife Society: Special topic. J Neurosurg 2014;121 (Suppl):2-15.
4. Paddick I, Lippitz B. A simple dose gradient measurement tool to complement the conformity index. J Neurosurg 2006;105 (Suppl):194-201.
5. Wu QR, Wessels BW, Einstein DB, Maciunas RJ, Kim EY, Kinsella TJ. Quality of coverage: Conformity measures for stereotactic radiosurgery. J Appl Clin Med Phys 2003;4:374-81.
6. Chagas Saraiva CW, Cardoso SC, Groppo DP, De Salles AA, de Ávila LF, Ribeiro da Rosa LA. Gamma Knife radiosurgery for vestibular schwannomas: Evaluation of planning using the sphericity degree of the target volume. PLoS One 2020;15:e0225638.
7. Petti PL, Larson DA, Kunwar S. Use of hybrid shots in planning Perfexion Gamma Knife treatments for lesions close to critical structures. J Neurosurg 2008;109 (Suppl):34-40.
8. Lindquist C, Paddick I. The Leksell Gamma Knife Perfexion and comparisons with its predecessors. Neurosurgery 2007;61:130-40.
9. Brown M, Ruckenstein M, Bigelow D, Judy K, Wilson V, Alonso-Basanta M, *et al.* Predictors of hearing loss after gamma knife radiosurgery for vestibular schwannomas: Age, cochlear dose, and tumor coverage. Neurosurgery 2011;69:605-13.