Analysis of Doses to Trigeminal Nerve, Brainstem in Gamma Knife Radiosurgery-A Dosimetric Study

VP Pandey
Department of Physics
Govt MVM College, Bhopal, M.p, India & Rancan Gammma Knife Centre, VIMHANS Hospital, New Delhi, India

Devi Prasad Pandey
Department of Medical Physics
Shyam Shah Medical College, REWA, M.P,India

Vinod K Gangwar
Department of Physics
MJP Rohilkhand University, Bareily, UP, India

Jayant Misra
Rancan Gammma Knife Centre, VIMHANS Hospital, New Delhi, India

Sanjay Dixit
Department of Physics
Govt MVM College, Bhopal, M.p, India

Abstract

Gamma Knife radiosurgery is a highly accurate and precise delivery system. Treatment of Trigeminal neuralgia (TN) is performed as a invasive frame fixation procedure in Gamma Knife radiosurgery. The prescription dose for TN is very high. Organ at risk (OAR) is brainstem which is adjacent to the target which has possibility to receive the very high target doses of TN. The present study is to analyse the dose distribution inside the tiny trigeminal nerve target and also to analyse the dose received in brainstem. Ten cases are considered in the present study to analyse the dose distribution in TN(Trigeminal Neuralgia) target and organ at risk. The treatment plan were analysed for target dose conformity, homogeneity and dose coverage. Gamma Plan version 8.3.1 is used for planning of cases.In the brainstem the volume doses D_{min}, D_{max}, D_{mean} were taken for analysing the doses in the brain stem. The mean value of maximum dose within the trigeminal nerve target was 91.04 $\pm$1.6 and minimum dose was 12±5.05. The mean conformity index was 1.4±0.235 and the homogeneity index was 2.018±0.035. The mean dose to brainstem was 1.17±0.23 and the mean value of maximum dose to brainstem was 15.83±2.2. The present study shows the superior sparing of brainstem and reasonable of target coverage. Use of 4mm Collimator and plugging provides the best result to spare brainstem and deliver the desired dose to the Root Entry Zone in Trigeminal Neuralgia.
Keywords: Trigeminal Nerve, Gamma Knife, Collimator

I. Introduction

A handful of studies have reported the outcome with the cyberknife radiosurgery of trigeminal neuralgia. This study is performed on the basis of such studies but on different treatment modality i.e Gamma Knife. H. Sudahar et al [1] have shown the doses on brainstem and trigeminal nerve with the cyberknife. We have used gamma knife for radiosurgery of trigeminal nerve and performed the study. A cohort of 10 patients were considered in this study with all the trigeminal neuralgia unilateral cases. Gamma Knife is a gold standard in terms of accuracy and precision of radiosurgical unit . Leksell Gamma Knife (Elekta Instrument AB, Stockholm, Sweden) is a dedicated unit for intracranial radiosurgery of defined indications. The unit consists of a radiation unit, treatment table, helmet collimators and Gamma Plan. The radiation unit contains 201 sources, which are arranged in five rings in the hemispherical central body having a radius of 40cm. Leksell Gamma Plan is the integrated computer planning system.

The Radiosurgery requires a high standard of accuracy and precision while treating with a radiosurgical unit. Trigeminal neuralgia (TN) is the 5th cranial nerve disorder, which results in unbearable facial pain in patients.[2-3] Apart from medications and hormone therapy external beam radiation therapy is a viable option to treat it. Trigeminal neuralgia surgery is an effective treatment for the 25 percent of patients who do not respond to medications or have negative side effects from medications. Knowing about surgical options is also valuable for patients whose pain is currently controlled by medications because trigeminal neuralgia pain can escalate quickly. Radiosurgery is one of the treatment options for TN.[4,5] Utilizing focused beams of radiation, this non-invasive procedure intentionally damages the trigeminal nerve, stopping the nerve from conducting pain signals to the area of short-circuiting. Since the beams are focused on the target, the procedure results in minimal damage to healthy tissue. Stereotactic Radiosurgery for TN is a one of the solution as the target is the smallest of all known radiosurgical targets. Gamma Knife is being used from long back to treat TN. [6-8]. It is an invasive procedure to make the head immobilize for proper targeting. [9-12] and this explains the extent of pain in patients. The cause for TN is the focal demyelination of trigeminal nerve root by vascular compression. [13] Generally, TN occurs unilaterally; however, occasionally may be bilateral.[14] There are three main treatment modalities for TN: medical treatments through drugs, surgical treatment and radiosurgery treatment.[15] Micro-vascular decompression (MVD) is a well known surgical treatment for TN.[16] Radiosurgery for TN has been performed either as a frame based or as a frameless radiosurgery. Frame based is an invasive method while frameless is a non-invasive method. Leksell Gamma Knife (Elekta Instruments, Stockholm, Sweden) radiosurgery is a frame based procedure, while Cyberknife (Accuray, Sunnyvale, USA) is an image guided frameless procedures. In the BrainLAB Novalis (BrainLAB A.G., Heimstetten, Germany) radiosurgery system, both the frame based and frameless procedures are being performed. The radiation dose to treat TN is very large when compared with all other radiosurgical procedures performed.

The dose in Gamma Knife is prescribed to a 50% isodose, and the prescription dose is between 35Gy to 40 Gy.[17-18] A maximum of 70 Gy to 90 Gy is delivered to the trigeminal nerve in the gamma knife. Similarly in cyberknife, the dose prescribed to 75% to 85% isodose and the prescription dose is 60Gy. This very high dose to the tiny trigeminal nerve necessitates very precise targeting. The high accuracy and presicion is a prerequisite for targeting trigeminal nerve. Especially, the organs at risk (OAR) doses should be restricted to their tolerance limit. Brainstem is the critical organ at risk near trigeminal nerve. The target is set at the point of impingement of the nerve and vascular structure targeted in this case. Treatment planning plays a crucial role in restricting the dose to the brain stem. The present study aims to analyse the dose distribution in the trigeminal nerve and in the brain stem in cases treated with Gamma Knife stereotactic radiosurgery system.

II. METHODOLOGY

Ten cases are considered in this study retrospectively.Out of these ten cases, seven were cases of TN in the left side, and three were of TN in the right side. Seven of them are males and three were female cases of TN. Appropriate visualization of the trigeminal nerve is an important task in TN treatment. The Magnetic resonance images of the cranium were acquired in 2mm slice thickness. The images were taken with and without contrast for the exact delineation of the target. With the help of these T2 MR images, the trigeminal nerve and the OARs were drawn into the images. The target comprises of trigeminal nerve and vascular structure both at the point of impingement. The brainstem is drawn exactly to spare it during the stereotactic radiosurgery irradiation.

A. Treatment Planning

Gamma Knife plans were created on the version 8.3.1 of Gamma Plan planning system of Elekta. Out of ten cases eight cases were planned with the 2 isocenter and rest two cases were treated with single isocentre plan. The smallest collimator helmet of 4mm is used in all the ten cases for planning. The dose prescription in all the cases were 45 Gy at 50% isodose. Eye plugging were put for sparing the eye lens from beam coming out of the path into eyes. The co ordinates are defined to get the exact isocentre in multi isocentre plans. Dose to brainstem was kept minimum in all the ten cases. The plans were made and evaluated.

B. Treatment Plan Evaluation

The target volume doses were evaluated from dose volume histogram (DVH). The maximum dose and minimum dose to the trigeminal nerve was evaluated. The dose conformity index and homogeneity index of the trigeminal nerve were also analysed. The formulae used to calculate the conformity index and the homogeneity index are given as follows.

$$\text{Conformity Index (CI)} = (V_{RI} \text{X } TV)/(TV_{RI})^2 \qquad \text{……………………………(1)}$$

Where V_{RI} is the overall volume including the target volume, receiving the prescription isodose or more, TV is the volume of the trigeminal nerve target, and TV_{RI} is the volume of the target which receives the prescription isodose or more. This conformity index was initially proposed in an inverse law by Paddick[30] and modified in the current form by Nakamura et al.[31]

$$\text{Homogeneity index (HI)} = D_{max}/D_{RI} \text{ ,[32]} \qquad \text{………………………………..(2)}$$

Where D_{max} is the maximum dose in the nerve target and D_{RI} is the prescription isodose. Brainstem doses were evaluated for minimum, mean and maximum dose.

III. RESULTS

The mean volume of the trigeminal nerve target was 72.07 mm^3. The minimum volume was 26.4 mm^3 and the maximum volume was 129.9 mm^3. The mean volume of the brainstem was 4.4±1.3cm^3. The dose distributions in the axial, sagittal and coronal sections in the MR images are shown in Figure 1, Figure 2 respectively.

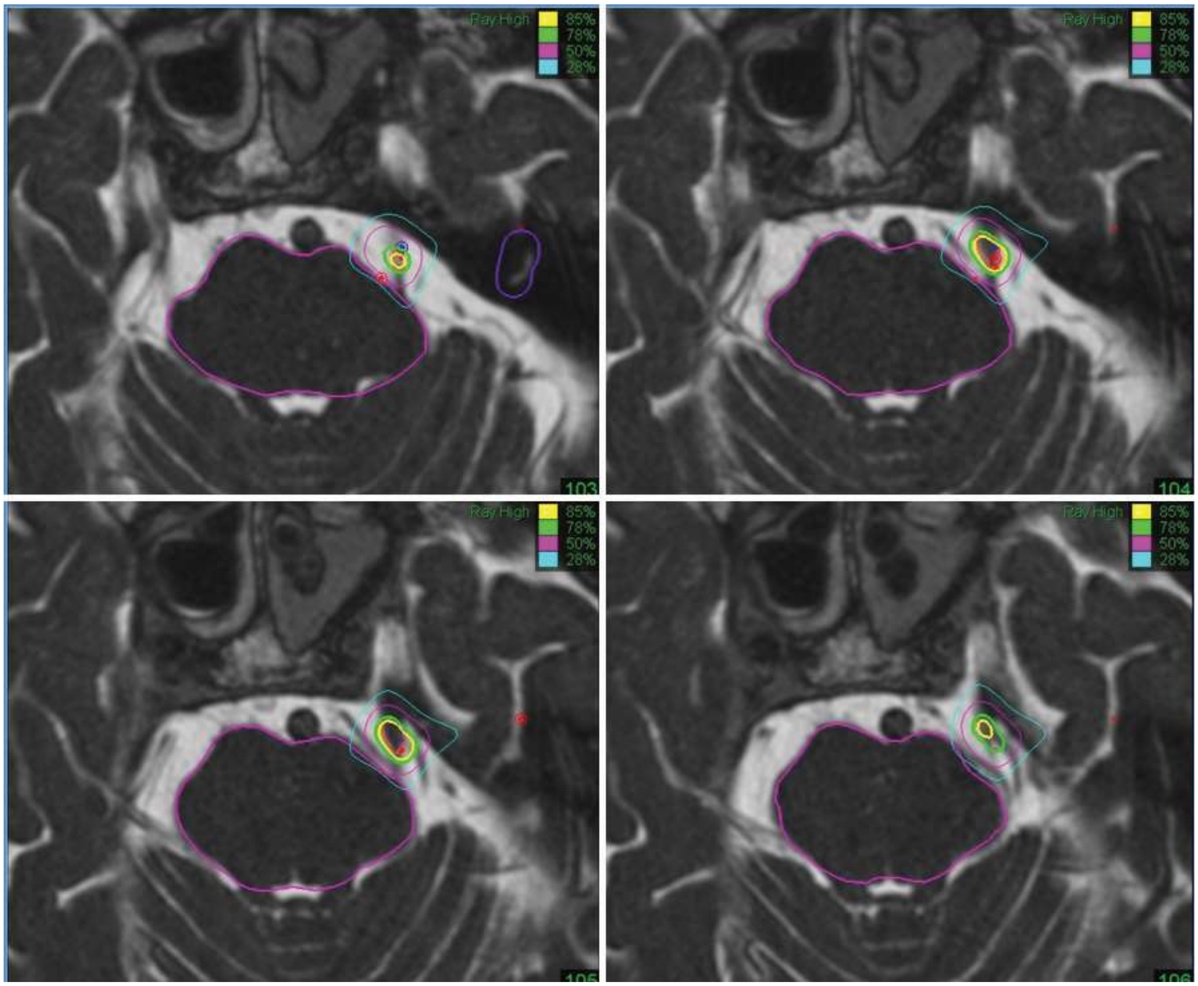

Table – 1
Target dose distribution analysis in terms of volume doses

Case No	*Target Volume*	*Volume doses of the trigeminal nerve target (Gy)*				
	(mm^3)	*$D_{98\%}$*	*$D_{90\%}$*	*$D_{50\%}$*	*$D_{30\%}$*	*$D_{10\%}$*
1	*55.4*	*15.7*	*25.8*	*59*	*68.2*	*81.1*
2	*26.4*	*11.6*	*18.7*	*66.9*	*80.6*	*84.8*
3	*58.3*	*21.8*	*31.8*	*61.7*	*69.4*	*79.9*
4	*89.2*	*11.8*	*17.2*	*53.6*	*64.4*	*78.1*
5	*56.7*	*16.1*	*24.2*	*64*	*71.3*	*78.8*
6	*129*	*8.2*	*12.7*	*48*	*62.5*	*73.4*
7	*69*	*17.5*	*27.6*	*61.1*	*68.5*	*78.2*
8	*49.9*	*35.4*	*58.1*	*75.8*	*79.4*	*84.4*
9	*56.9*	*25.2*	*32.3*	*58.8*	*67.9*	*79.9*
10	*129.9*	*27.6*	*38.1*	*60.9*	*67.6*	*77.1*
Mean±SD	*72.07±32.2*	*19.09±7.96*	*28.6±12.2*	*60.9±7.04*	*69.9±5.5*	*79.57±3.19*

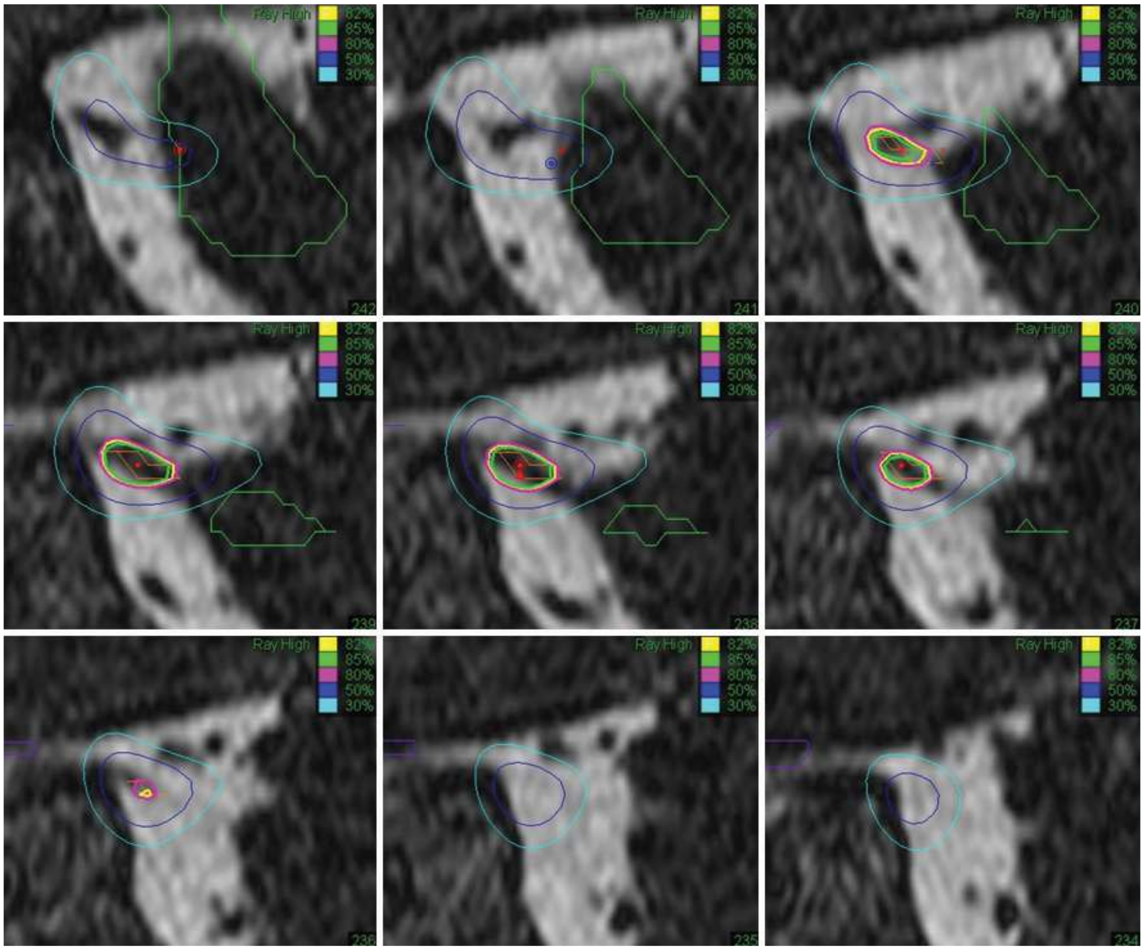

Table – 2
Target dose distribution analysis in terms of mean dose, minimum and maximum point doses

Cases	*Trigeminal Nerve Target Doses (Gy)*		
	Minimum	*Maximum*	*Mean*
1	*8.1*	*91.6*	*52.0± 26.9*
2	*8.0*	*89.3*	*57.7±26.0*
3	*17.0*	*90.8*	*58.7±17.3*
4	*8.0*	*90.8*	*49.5±22.2*
5	*8.2*	*89.6*	*57.4±20.3*
6	*6.4*	*90.6*	*44.3±23.3*
7	*9.6*	*92.0*	*57.6±18.2*
8	*21.1*	*90.7*	*73.1±11.7*
9	*15.7*	*89.8*	*57.6±16.7*
10	*17.9*	*95.2*	*59.2±14.7*

A. Trigeminal Nerve Dose

The $D_{98\%}$, $D_{90\%}$, $D_{50\%}$, $D_{30\%}$ and $D_{10\%}$ values of the trigeminal nerve target are shown in table 1. $D_{98\%}$ is a measure of the minimum dose within the trigeminal nerve target. The mean value of $D_{98\%}$ was 19.09±7.96.The maximum and the minimum values of $D_{98\%}$ were 35.4 Gy and 8.2 Gy, respectively. Similarly, $D_{10\%}$ is the measure of maximum dose within the trigeminal target. $D_{10\%}$ was ranging between 73.4 Gy and 84.8 Gy. The percentage volume of the trigeminal nerve target receiving 100% of the prescribed dose, $V_{100\%}$, was 98%.The mean values of CI and the HI were 1.4±0.23 and 2.01±0.03 respectively. The mean value of the prescribing isodose was 50%. The conformity and homogeneity index are tabulated in Table no.3. The mean maximum dose was 91.04±1.6 Gy, and this maximum point dose was varying between 95.2 Gy and 89.3 Gy.

B. Brainstem Dose

The $D_{1\%}$, $D_{2\%}$, $D_{5\%}$ and $D_{10\%}$ values of the OAR brainstem are shown in Table 4. The mean brainstem dose and the maximum point dose in the brainstem are also shown in Table 4. The volume dose $D_{1\%}$, and $D_{2\%}$ are representing the maximum doses in the brainstem, while $D_{5\%}$ and $D_{10\%}$ are representing the degree of dose fall in the brainstem. The mean values of $D_{1\%}$, $D_{2\%}$,$D_{5\%}$ and $D_{10\%}$ were 9.46±1.05Gy,7.86 ±1.28 Gy,4.87±0.87Gy and 2.94±0.8Gy respectively. The maximum point dose was varying between 12.3 Gy and 20.9 Gy and the mean value was 15.83±2.2 Gy.

Table – 3
Target dose conformity, homogeneity analysis

Case No	*Conformity Index*	*Homogeneity Index*	*Prescribing Isodose(%)*	*$V_{100\%}$(%)*
1	1.39	2.03	50	98
2	1.52	1.98	50	99
3	1.28	2.01	50	98
4	1.67	2.01	50	99
5	1.36	1.99	50	98
6	1.92	2.01	50	98
7	1.30	2.04	50	99
8	1.05	2.01	50	98
9	1.30	1.99	50	98
10	1.21	2.11	50	98
Mean±SD	1.4±0.235	2.018±0.035		

Table – 4
Brainstem dose analysis

Case No	*Brainstem*		*Brainstem doses (Gy)*				
	Volume (cc)	*$D_{1\%}$*	*$D_{2\%}$*	*$D_{5\%}$*	*$D_{10\%}$*	*Max*	*Mean*
1	2.4	9	8.7	4.7	2.5	10	1.3±2.3
2	3.8	10.6	9.2	6.1	3.8	11.4	1.4±2.1
3	2.8	9.6	9.0	6.1	3.8	10.9	1.3±2.1
4	4.8	10	8.2	5.6	4.0	10.1	1.5±2.0
5	4.2	10.1	9.3	3.5	1.2	11.1	0.8±2.4
6	6.9	7.8	6.1	4.3	3.1	11.9	1.3±1.4
7	5.2	9.8	7.6	5.0	3.0	10.2	1.0±1.9
8	3.8	7.5	5.3	3.7	2.7	10.9	1.3±1.2
9	6.5	10.9	8.2	5.3	3.1	10.2	1.0±1.9
10	3.6	9.3	7.0	4.4	2.2	11.3	0.8±1.6

IV. Discussion

The maximum dose to the target segment of the trigeminal nerve is a matter of concern in the radiosurgical treatment of Trigeminal Neuralgia. In Gamma Knife radiosurgery of TN, the maximum dose often crosses 85 Gy.[33,34,35] Adler et el [36] is reporting a maximum dose in trigeminal target nerve in Cyberknife radiosurgery is 73.5 Gy. Though there is a difference in the maximum dose between the Gamma Knife radiosurgery and Cyberknife radiosurgery the clinical correlations are showing applicable success rate in both the cases. [37-40]

The mean prescribing isodose line in the present study is 50% and the mean coverage is 98%. This shows that about 2 % of the tiny trigeminal target is receiving dose lesser than 12 Gy. The mean conformity index is 1.4±0.235 and mean homogeneity index is 2.018±0.035.

The target dose coverage usually lowered because of the dose restriction to the brainstem. The mean value of the $D_{1\%}$ in the brainstem is 9.46 Gy while the mean maximum point dose in the brain stem is 10.9 Gy. The brainstem dose gradient analysis by $D_{2\%}$, $D_{5\%}$ and $D_{10\%}$ are showing a better dose fall off of dose within the brainstem.

V. Conclusion

The results of the present study are showing superior sparing of brain stem and reasonable of target coverage, It is necessary to correlate the dose distribution with the clinical outcomes through follow ups. The target segment of the trigeminal nerve should be irradiated with an adequate dose to reduce the pain due to TN. The present study shows that the point dose maximum in Gamma Knife radiosurgery of TN is about 90Gy. The 4mm collimator used for the study to limit the dose within the target. Though there is a spillage of dose outside the target, it is not towards the critical OAR brainstem.

REFERENCES

[1] H. Sudahar, P. G. G. Kurup, V. Murali, and J. Velmurugan . Dosimetric analysis of trigeminal nerve, brain stem doses in CyberKnife radiosurgery of trigeminal neuralgia. J Med Phys. 2012 Jul-Sep; 37(3): 124–128. doi: 10.4103/0971-6203.99225.
[2] Oh IH, Choi SK, Park BJ, Kim TS, Rhee BA, Lim YJ. The treatment Outcome of elderly patients with idiopathic trigeminal neuralgia: Micro-vascular decompression versus gamma knife radiosurgery. J Korean Neurosurg Soc 2008; 44:199-204.
[3] Brisman R. Bilateral trigeminal neuralgia. J Neurosurg 1987; 67:44-8.
[4] Mendoza N, Illingworth RD. Trigeminal neuralgia treated by microvascular decompression: A long-term follow-up study. Br J Neurosurg 1995; 9:13-9.
[5] Brisman R. Surgical treatment of trigeminal neuralgia. Semin Neurol 1997; 17:367-72.
[6] Zakrzewska JM, Patsalos PN. Long-term cohort study comparing medical (oxcarbazepine) and surgical management of intractable trigeminal neuralgia. Pain 2002; 95:259-66.
[7] Obermann M. Treatment options in trigeminal neuralgia. Ther Adv Neurol Disord 2010; 3:107-15.
[8] Chakravarthi PS, Ghanta R, Kattimani V. Microvascular decompression treatment for trigeminal neuralgia. J Craniofac Surg 2011; 22:894-8.
[9] Sindou M, Leston J, Decullier E, Chapuis F. Microvascular decompression for primary trigeminal neuralgia: Long-term effectiveness and prognostic factors in a series of 362 consecutive patients with clear-cut neurovascular conflicts who underwent pure decompression. J Neurosurg 2007; 107:1144-53.
[10] McNatt SA, Yu C, Giannotta SL, Zee CS, Apuzzo ML, Petrovich Z. Gamma Knife radiosurgery for trigeminal neuralgia. Neurosurgery 2005; 56:1295-301.
[11] Kondziolka D, Zorro O, Lobato-Polo J, Kano H, Flannery TJ, Flickinger JC, et al. Gamma Knife stereotactic radiosurgery for idiopathic trigeminal neuralgia. J Neurosurg 2010; 112:758-65.
[12] Tang CT, Chang SD, Tseng KY, Liu MY, Ju DT. CyberKnife stereotactic radiosurgical rhizotomy for refractory trigeminal neuralgia. J Clin Neurosci 2011; 18:1449-53.
[13] Peddada AV, Sceats DJ, White GA, Bulz G, Gibbs GL, Switzer B, et al. CyberKnife radiosurgery for trigeminal neuralgia: Unanticipated iatrogenic effect following successful treatment. J Neurosurg 2011;115:940-4
[14] Zahra H, Teh BS, Paulino AC, Yoshor D, Trask T, Baskin D, et al. Stereotactic radiosurgery for trigeminal neuralgia utilizing the BrainLAB Novalis system. Technol Cancer Res Treat 2009; 8:407-12.
[15] Chen JC, Rahimian J, Rahimian R, Arellano A, Miller MJ, Girvigian MR. Frameless image-guided radiosurgery for initial treatment of typical trigeminal neuralgia. World Neurosurg 2010; 74:538-43.
[16] Rogers CL, Shetter AG, Fiedler JA, Smith KA, Han PP, Speiser BL. Gamma Knife radiosurgery for trigeminal neuralgia: The initial experience of The Barrow Neurological Institute. Int J Radiat Oncol Biol Phys 2000; 47:1013-9.
[17] Henson CF, Goldman HW, Rosenwasser RH, Downes MB, Bednarz G, Pequignot EC, et al. Glycerol rhizotomy versus Gamma Knife radiosurgery for the treatment of trigeminal neuralgia: An analysis of patients treated at one institution. Int J Radiat Oncol Biol Phys 2005; 63:82-90.
[18] Paddick I. A simple scoring ratio to index the conformity of radiosurgical treatment plans. Technical note. J Neurosurg 2000; 93 Suppl 3:219-22.