ScientificScholar®
Knowledge is power
Publisher of Scientific Journals

www.surgicalneurologyint.com

Surgical Neurology International

Editor-in-Chief: Nancy E. Epstein, MD, Clinical Professor of Neurological Surgery, School of Medicine, State U. of NY at Stony Brook.

SNI: Neuro-Oncology

Editor
Mitsutoshi Nakada, MD
Kanazawa University, Ishikawa, Japan

SNI
Open Access

Original Article

Long-term outcomes of rotating gamma knife for vestibular schwannoma: A 4-year prospective longitudinal study of 89 consecutive patients in Vietnam

Hung Dinh Kieu[1], Duong Ngoc Vuong[2], Khoa Trong Mai[2], Phuong Cam Pham[2], Tam Duc Le[1]

[1]Department of Neurosurgery and Spine Surgery, Hanoi Medical University Hospital, [2]The Nuclear Medicine and Oncology Center, Bach Mai Hospital, Hanoi, Vietnam.

E-mail: Hung Dinh Kieu - kieudinhhung2008@gmail.com; Duong Ngoc Vuong - ngocduongbvk@yahoo.com; Khoa Trong Mai - khoa.maitrong@gmail.com; Phuong Cam Pham - phamcamphuong@gmail.com; *Tam Duc Le - leductam1413@gmail.com

***Corresponding author:**
Tam Duc Le,
Department of Neurosurgery and Spine Surgery, Hanoi Medical University Hospital, Hanoi, Vietnam.

leductam1413@gmail.com

Received : 10 July 2021
Accepted : 10 November 2021
Published : 30 November 2021

DOI
10.25259/SNI_687_2021

Quick Response Code:

ABSTRACT

Background: Microsurgical total removal of vestibular schwannoma (VS) is the definitive treatment but has a high incidence of postoperative neurological deficits. Rotating Gamma Knife (RGK) is a preferred option for a small tumor. This study aims to evaluate long-term neurological outcomes of RGK for VS.

Methods: This prospective longitudinal study was conducted at the Nuclear Medicine and Oncology Center, Bach Mai Hospital, Hanoi, Vietnam. Eighty-nine consecutive patients were enrolled from October 2011 to October 2015 and followed up to June 2017. RGK was indicated for VS measuring <2.2 cm, while RGK for tumors measuring 2.2–3 cm was considered in patients with severe comorbidities, high-risk surgery, and who denied surgery. Concurrently, VS consisted of newly diagnosed, postoperative residual, and recurrent tumors. Patients with neurofibromatosis type 2 were excluded from the study. Primary outcomes were radiological tumor control rate, vestibulocochlear functions, facial and trigeminal nerve preservation. Stereotactic radiosurgery was performed by the Rotating Gamma System Gamma ART 6000.

Results: The tumors were measured 20.7 ± 5.6 mm at pre treatment and 17.6 ± 4.1 mm at 3-year post treatment. The mean radiation dose was 13.5 ± 0.9 Gy. Mean follow-up was 40.6 ± 13.3 months. The radiological tumor control rate was achieved 95.5% at 5-year post treatment. The hearing and vestibular functions were preserved in 70.3% and 68.9%, respectively. The facial and trigeminal nerve preservation rates were 94.4% and 73.3%, respectively.

Conclusion: RGK is an effective and safe treatment for VS measuring ≤3 cm with no significant complications during long-term follow-up.

Keywords: Neurological outcomes, Prospective, Rotating gamma knife, Tumor control rate, Vestibular schwannoma

INTRODUCTION

Vestibular schwannoma (VS), an intracranial extra-axial tumor, is originated from the Schwann cell sheath of either vestibular or cochlear nerve of the eighth cranial nerve. VS comprises about 80% of the cerebellopontine angle tumors and 6–8% of all intracranial tumors. Approximately 65–75% of tumors stem from the inferior branch of the vestibular nerve of the eighth cranial nerve.[14,15]

Treatment options of VS include surgical removal of the tumor, controlling tumor growth by stereotactic radiotherapy or radiosurgery, and careful serial observation. Surgical total resection remains the choice of tumor eradication. Despite significant advances and innovations in microsurgery technique, microsurgical excision of VS had many severe complications such as disequilibrium, lower cranial nerve palsies, cerebrospinal fluid leakage, and facial nerve palsy.[18,21,23] In contrast, stereotactic radiosurgery (SRS, Gamma Knife®, Cyberknife®) halts tumor growth using radiation delivered maximally to target tissues while minimizing adjacent exposure to the normal brain. The previous studies have proved Gamma Knife's efficacy and safety in treating VS.[8,11,16,20,22,26,29] In the most recent report, the 2-year and 4-year clinical control tumor rates were 98% and 96%, respectively.[28] The serviceable hearing preservation rate was 72.2%.[28]

The rotating gamma knife system (RGK) is a hybrid with features of both classical Gamma Knife and linear accelerator-based radiosurgery systems.[9] Compared with classical Gamma Knife, the rotating gamma system had less spontaneously emitted radioactive cobalt-60 sources, higher precision of the isocenter location, more beam stability, and less scattered radiation to the patient. Therefore, the RGK had advantages in the treatment of skull base tumors. However, more data on the long-term efficacy and safety of RGK in the management of VS is warranted. This study aims to evaluate the long-term neurological outcomes of RGK for VS in Vietnam.

MATERIALS AND METHODS

Study design

This was a prospective longitudinal single-center study. From October 2011 to October 2015, 89 patients with VSs were treated by RGK. The follow-ups lasted until June 2017. These cases were selected consecutively. This study was conducted at the nuclear medicine and Oncology Center, Bach Mai Hospital. Bach Mai Hospital, a tertiary referral hospital, was established in 1911 by the French and is considered one of Vietnam's largest hospitals. This is an academic and community hospital.

According to our institutional practices, RGK was recommended as the primary treatment for minimally symptomatic VSs measuring <2.2 cm in maximal diameter. In contrast, microsurgical resection was recommended as first-line therapy for patients presenting with debilitating pre treatment symptoms, larger tumors with maximal diameter >3 cm or mass effect on surrounding structures.[10,16,28] In the case of symptomatic tumors measuring from 2.2 cm to 3 cm, RGK was considered for patients with severe comorbidities, high-risk surgery, and who denied surgery. The final treatment decision was made based on a thorough pre treatment consultation with patients. We included in our study 89 consecutive patients fulfilling the following inclusion criteria: all patients with VS received RGK as the protocol mentioned above. VSs consisted of newly diagnosed, postoperative residual, and recurrent tumors. Patients affected by neurofibromatosis type 2 were excluded from the study. On magnetic resonance imaging (MRI), the VS features were an intracranial extra-axial tumor of the cerebellopontine angle, which had an intracanalicular component, and widened the porus acusticus. This tumor was demarcated with adjacent tissues and showed avid homogenous or heterogeneous contrast enhancement.

Our Institutional Review Board approved the experimental protocol as well as the informed consent for this study. All patients with VS were consulted by interdisciplinary healthcare professionals, including neurosurgeons, neurologists, radiologists, radiation oncologists, pathologists, and otolaryngologists. The consensus treatment plan was discussed with the patients and their family members.

On the treatment day, after being administered a local anesthetic for immobilization, the patients underwent the application of a stereotactic head frame. Pre treatment volumetric MRI sequences included 1-mm, axial, T1-weighted, contrast-enhanced images, 1–1.5-mm, axial, T2-weighted volume images, and 3-mm, T2, whole-head imaging. The SRS scenario was planned by the software. Based on the tumor's contour, site, and size, the different shots (18 mm, 14 mm, 8 mm, and 4 mm) were designed to aim that the 50% isodose line circumscribed the tumor. The 40%, 30%, and 20% isodose lines were evaluated. The dose-volume histograms (DVH) were used to assess the SRS plans. Stereotactic radiosurgery was performed using the Rotating Gamma System Gamma ART-6000™ (American radiosurgery Inc., San Diego, CA, USA). The prescribed SRS dose was 10–16 Gy to the 50% isodose line. The doses for brain stem, cranial nerves (V, VII, and VIII), and cochlea were generally kept below 14 Gy, 12 Gy, and 4 Gy, respectively. Radiation delivery to the brainstem was estimated in a dose-volume fashion (DVH-based). We planned to keep 12 Gy-volume (V12) = 0 and V10 <1 cc to avoid possible issues with focal radionecrosis. In the case of postoperative residual and recurrent tumors, we had difficulty determining cranial nerves (V, VII, and VIII) on MRI. Therefore, empirically estimated doses for these cranial nerves were calculated based on multidisciplinary discussions which included neurosurgeons, radiologists, and radiation oncologists. Post treatment follow-up assessments were performed at 3, 6, 12, 24, and 36 months.

The work has been reported in line with the PROCESS criteria.[1]

Statistical analysis

The patients were assessed clinically and radiologically. Primary outcomes were radiological tumor control rate, hearing function, vestibular function, facial nerve palsy, and trigeminal neuralgia. Hearing function was evaluated by Gardner-Robertson classification. Facial nerve deficit was clinically assessed using the House-Brackmann index before and after treatment. Different symptomatic outcomes analyzed included lateralized headache, tinnitus, vertigo/dizziness/disequilibrium, trigeminal neuralgia, and secondary malignancies. Radiographic tumor control was defined based on the time from gamma knife radiosurgery (GKRS) until the development of either asymptomatic or symptomatic radiographic progression. Radiographic progression was defined as persistently increased maximal tumor diameter by at least 2 mm than the last MRI within at least 6 months. Trigeminal neuropathy was defined as new facial numbness or trigeminal neuralgia as reported in the patient chart. It was recorded as either present or absent. The rate of new trigeminal neuropathy was calculated as the percentage of patients with trigeminal neuropathy at follow-up. Vestibular nerve dysfunction was assessed by the presence or absence of balance difficulty before and after treatment. The vestibular nerve dysfunction was new if it was reported after but not before GKRS, and it was written as worse if the patient record explicitly stated that the functioning was worse after GKRS.

Data analysis was performed using STATA® version 14.0 (StataCorp., Lakeway Drive College Station, Texas, USA). Statistical significance was set arbitrarily at $P < 0.05$. The quantitative variables were presented as mean ± standard deviation if the data were normal distribution and were shown as the median and interquartile range if the data were non-normal distribution. The qualitative variables were presented as frequency and proportions. We used the Wilcoxon signed-rank test to compare the difference between the two paired groups. Kaplan–Meier estimator evaluated radiological progression-free survival.

Ethical considerations

The Institutional Review Board at Nuclear Medicine and Oncology Center of Bach Mai Hospital and Hanoi Medical University, Hanoi, Vietnam, approved data collection, analysis, and publication of this study. The study was performed within ethical standards. All potential participants were given information on the study's purpose, the associated risks, and benefits and were required to provide written informed consent before inclusion in the study. Parents or legal guardians provided written consent for participants aged <18 years.

RESULTS

Participants and descriptive data

A total of 89 patients with VS were treated by RGK. Thirty-one patients were lost to follow-up after 4 years, precluding a longer period of surveillance. Patient characteristics and descriptive data are tabulated in [Table 1]. Females accounted for 66.3% of patients, and the mean age was 49.9-years-old. Headache (89.9%), tinnitus (92.1%), and hearing loss (71.9%) were the most common symptoms. Fifty-eight out of 89 patients had a new diagnosis of VS and no previous interventions. Histopathology of schwannoma was confirmed in 27 out of 89 cases. The mean maximal diameter of the tumor was 20.7 ± 5.6 mm. On MRI, Koos Grades II and III were reported in 42.7% and 46.1%. No patient presented peritumoral edema before RGK treatment. Regarding hearing function, Gardner-Robertson Grade III and Grade IV, V accounted for 50.6% of the cohort. The mean duration of follow-ups was 40.6 ± 13.3 months. The mean radiation dose was 13.5 ± 0.9 Gy and the mean shot was 6.2 ± 4.4 shots. In radiological follow-ups, the mean maximal diameter of tumor gradually decreased to 19.8 ± 4.7 mm at 1-year post treatment, 18.5 ± 5.9 mm at 2-year post treatment and 17.6 ± 4.1 mm at 3-year post treatment [Table 2] and [Figure 1].

Outcomes

Headache, tinnitus, and vertigo improved significantly post treatment [Table 3]. Two cases (2.2%) had pre treatment obstructive hydrocephalus and received ventriculoperitoneal shunt before RGK treatment. No new-onset hydrocephalus was present at post treatment follow-ups. New-onset hearing impairment was reported in 15 cases [Table 3]. We noted four new-onset facial nerve palsy after radiosurgery. The hearing function and vestibular function were preserved in 70.3% and 68.9%, respectively. The facial and trigeminal nerve preservation rates were 94.4% and 73.3%, respectively [Tables 4]. Radiation dose ≤13Gy had a significantly higher rate of facial nerve and hearing preservation than radiation doses >13Gy [Table 5].

Regarding post treatment complaints, insomnia (31.4%), anorexia (22.5%), and headache (20.2%) were the most common [Table 6]. These complaints occurred in a short-term period and then disappeared spontaneously. Four cases underwent surgical resection due to progressive tumor growth while on follow-up. Overall, radiological tumor control at 1-year, 2-year, 3-year, 4-year and 5-year post treatment was 100%, 98.8%, 98.7%, 96.6%, and 95.5%, respectively, [Figure 2].

Table 1: Patient characteristics and descriptive data.

Baseline characteristics	Vestibular schwannoma (*n*=89)
Gender	
Male	30 (33.7%)
Female	59 (66.3%)
Age (mean, SD) (yr)	49.9±5.9
Clinical presentation	
Headache	80 (89.9%)
Tinnitus	82 (92.1%)
Nausea, vomiting	20 (23.0%)
Hearing loss	64 (71.9%)
Facial pain	23 (25.8%)
Facial palsy	22 (24.7%)
Incidental findings	5 (6.7%)
Previous treatment	
Tumor resection	27 (30.3%)
Ventriculoperitoneal shunt	2 (2.2%)
Radiotherapy/Radiosurgery	2 (2.2%)
No intervention	58 (65.3%)
Histopathology	
Schwannoma	27 (30.3%)
No histopathology	62 (69.7%)
Tumor site	
Left	42 (47.2%)
Right	45 (50.6%)
Bilateral	2 (2.2%)
Tumor maximal diameter (mean, SD) (millimeter)	20.7±5.6
Koos classification	
Grade 1	7 (7.7%)
Grade 2	34 (42.7%)
Grade 3	41 (46.1%)
Grade 4	7 (3.4%)
Peritumoral edema before treatment	0
Peritumoral edema after treatment	8
Gardner-Robertson classification	
Grade I	15 (16.7%)
Grade II	29 (32.7%)
Grade III	23 (25.8%)
Grade IV, V	22 (24.8%)
Follow-up duration (mean, SD) (month)	40.6±13.3
Radiation dose (mean, SD) (Gy)	13.5±0.9
Shots (mean, SD)	6.2±4.4
RGK time (mean, SD) (minutes)	52.9±20.5
Dose distributions to OARs	
Brain stem	<14 Gy
Cranial nerves (V, VII, and VIII)	<12 Gy
Cochlea	<4 Gy
Radiation delivery to the brainstem	
12 Gy-volume (V12)	0
10 Gy-volume (V10)	<1cc

SD: Standard deviation, RGK: Rotating Gamma Knife

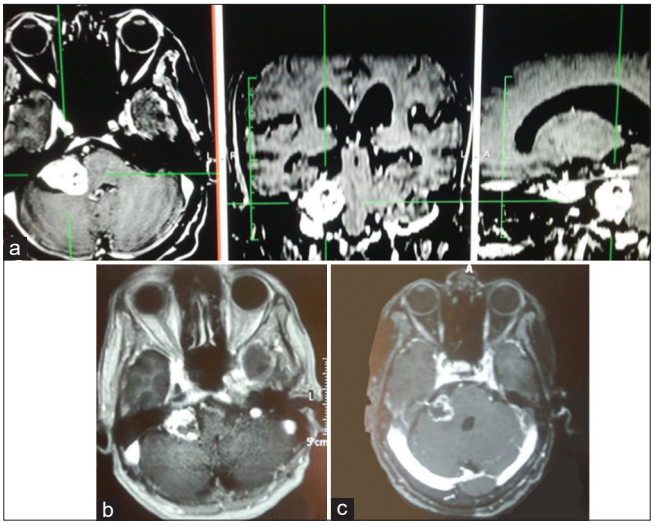

Figure 1: A 71-year-old female presented to our hospital with a complaint of headache and hearing loss on the right side for 12 months before admission. (a) Brain MRI showed a right vestibular schwannoma with Koos Grade III. MRI showed tumor necrosis and a remarkable decrease in size at 6-month (b) and 24-month (c) post treatment.

DISCUSSION

KEY RESULTS

For 4 years, 89 patients with VS were treated by RGK. The mean radiation dose was 13.5 ± 0.9 Gy. The mean duration of follow-ups was 40.6 ± 13.3 months. The radiological tumor control rate was 95.5% at 4-year post treatment. The most relieving symptoms were headache (89.9–5.6%) and tinnitus (92.1– 52.8%). The hearing function and vestibular function were preserved in 70.3% and 68.9%, respectively. The facial and trigeminal nerve preservation rates were 94.4% and 73.3%, respectively.

Interpretations

Radiation dose selection and tumor control rate

Prescription doses must balance between late perilesional toxicity and effective tumor control. In theory, low-dose rates may reduce focal toxicity by better preserving surrounding normal tissues, potentially compromising tumor control. In our study, the mean radiation dose was 13.5 Gy (range 10–16 Gy). This is in good agreement with Lunsford (mean 13 Gy), Boari (mean 13 Gy, range 11–15 Gy),[5,20] Bailo,[3,4] and Smith (mean 12 Gy, range 11–16.8 Gy).[28] In these studies, tumor control rates ranged from 95% to 98% for primary VS and approximately 90% for residual and recurrent

Table 2: Changes in tumor size during follow-ups.

Tumor size (mm)	Pre treatment (n=89)	Post treatment			
		6 months (*n*=89)	12 months (*n*=89)	24 months (*n*=80)	36 months (*n*=58)
Mean±SD	20.7±5.6	20.3±5.4	19.8±4.7	18.5±5.9	17.6±4.1
Min–max	9–30	9–29	8–28	6–26	4–25
P-value[a]	-	0.277	0.359	0.461	0.227

[a]Wilcoxon signed-rank test

Table 3: Signs and symptoms during follow-ups.

Symptoms	Pre treatment (*n*)	Post treatment (*n*)			
		Improvement	Worsening	No change	New-onset
Tinnitus	82	35	15	39	0
Headache	79	49	30	5	0
Hearing impairment	64	3	4	42	15
Vertigo	29	12	9	8	0
Trigeminal neuralgia	15	6	4	5	3
Facial nerve dysfunction	22	0	0	22	3

Table 4: House-Brackmann facial paralysis scale for post- and pre-treatment.

House-Brackmann facial paralysis scale	Previous treatment (*n*=31)		No previous treatment (*n*=58)	
	Pre radiotherapy	Post radiotherapy	Pre radiotherapy	Post radiotherapy
Grade I	10	9	57	55
Grade II	4	4	1	3
Grade III	12	13	0	0
Grade IV	5	5	0	0
Grade V, IV	2	2	0	0

Table 5: Correlation between radiation dose and neurological preservation.

	Radiation dose>13 Gy	Radiation dose≤13 Gy	*P*-value*
Facial nerve preservation			
Yes	43	41	0.046
No	4	0	
Hearing preservation			
Yes	21	28	0.0118
No	14	4	
Trigeminal nerve preservation			
Yes	6	5	0.91
No	4	3	

*Fisher exact test

VS.[4,5,17,24,28] However, low-dose radiosurgery of Huang (mean 11Gy, range 10–12 Gy),[13] Horiba (mean 11.9 Gy, range 11–12 Gy),[21] and Schumacher (mean marginal dose 11 Gy)[27] had lower tumor control rate (91–93%). Andrew *et al*. reported tumor control rate at 5-year post treatment was 91%, at mean radiation doses of 11 Gy.[2]

Functional neurological preservation

[Table 7] illustrates the recent results of cranial nerve function preservation after low-dose GKRS for VSs.[28,27,12,3,19,5] Regarding hearing function, Gardner-Robertson Grade III-V accounted for 50.6%. New-onset hearing

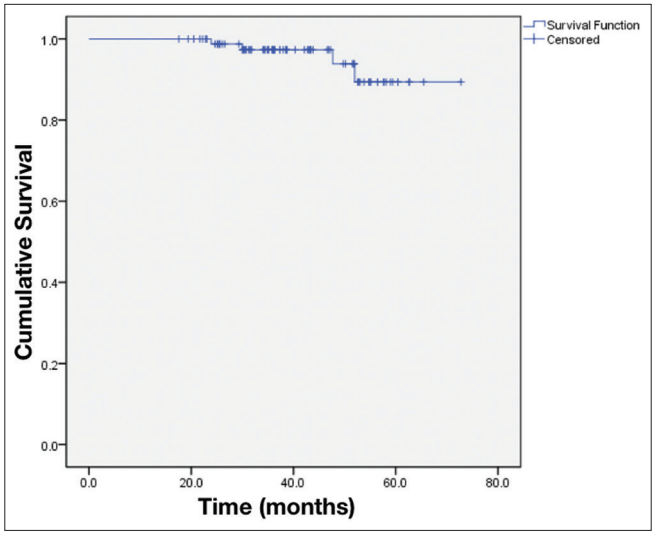

Figure 2: Kaplan–Meier Survival curves for radiological progression-free survival.

Table 6: Temporary post treatment complaints of rotating gamma knife for vestibular schwannoma.

Post treatment complaints	Frequency (%)
Insomnia	28 (31.4)
Mouth dryness	15 (16.8)
Anorexia	20 (22.5)
Alopecia	6 (6.7)
Seizures	10 (11.2)
Bleeding	6 (6.7)
Skin inflammation	3 (3.4)
Nausea and vomiting	
Worsen	10 (11.2)
New-onset	6 (6.7)
Headache	
Worsen	14 (15.7)
New-onset	4 (4.5)

impairment was reported in 15/89 cases. This is consistent with Ignacio's findings. The hearing function was worse in postoperative patients than in non-operative patients.[6] According to Regis's study, hearing function preservation was 84%, and tumor control rates were 97%.[25] Horiba illustrated that Gardner-Robertson hearing class before irradiation, Koos tumor stage, the extension of the tumor up to fundus, the nerve of tumor origin, presence of cystic changes in the tumor, and cochlea dose demonstrated no statistically significant association with preservation of the serviceable hearing after radiosurgery.[12] Coughlin's systematic review also proved that the hearing preservation rate was not dependent on tumor size, patient age, radiotherapy technique, fractionation, or SRS dose. However, hearing preservation rates changed significantly during follow-ups after radiotherapy.[7]

Pretreatment facial nerve palsy was observed in 24.7% of cases, in which 23.6% of patients had a previous surgical resection. Notwithstanding this, new-onset of transient facial nerve palsy post treatment was reported in four cases with one case recovering after 24 months. The latter is also in keeping with findings from other groups where facial nerve preservation was in the range of 95–100%.[3,5,20,24,27] However, in residual and recurrent VS, the new-onset facial nerve palsy following GKRS might prove higher (8.9%).[4]

Due to posterior compression of VS, 3/89 (3.3%) cases had a new-onset of trigeminal neuralgia. This value was scarcely distinguishable from previous results.[3,5,20,27] In contrast, in residual and recurrent VS, pre treatment trigeminal neuralgia was 28.9%, and 5.6% of cases had new-onset trigeminal neuralgia post treatment. The patients with a VS >30 mm in a maximum axial diameter had a slightly higher risk of trigeminal neuralgia than those with a VS <30 mm ($P = 0.092$).[4]

Table 7: Preservation of cranial nerve function after low-dose Gamma Knife radiosurgery for vestibular schwannomas.

Author, year of publication	Marginal dose (Gy)	Length of follow-up (months)	Rates of hearing preservation	Rates of facial nerve preservation	Rates of trigeminal nerve preservation
Smith *et al.*, 2019[28]	12	29.8	72.2%	90%	79.2%
Schumacher *et al.*, 2017[27]	11	42	56%	100%	96.7%
Horiba *et al.*, 2016[12]	11.9	24–99 (median, 56)	57%	-	-
Bailo *et al.*, 2016[3]	13	79.4	31.3% (66.7% among patients with Gardner-Robertson I)	94.9%	93.2%
Lipski *et al.*, 2015[19]	11–12 (mean, 11.5)	24–84 (median, 48)	77%	100%	100%
Boari *et al.*, 2014[5]	11–15 (median, 13	36–157 (mean, 75.7)	49%	98.9%	98.2%
Our series	13.5	40.6	70.3%	94.4%	73.3%

Complications

Regarding the safety of RGK, no mortality case was reported even in elderly patients with severe comorbidities. Insomnia (31.4%) and anorexia (22.5%) were the most common complaints. Nevertheless, headache, insomnia, and anorexia were usually relieved by medication (usually within three days). Despite this, symptoms lasted up to 1 month in some patients. Brain edema was determined by magnetic imaging resonance. In this context, edema was reported as a complication of radiosurgery when it got worse or fully evolved after treatment, usually at a rate of 3-month post radiosurgery. In this study, eight cases had post treatment brain edema (21.6%), generally presenting with headache, nausea, and vomiting. All of all these particular cases were treated with corticoid therapy and their symptoms relieved after several weeks to 1 month. This is also in keeping with Bailo *et al.*, observing signs of adverse radiation effect in 6/59 cases.[3] However, the studies from Schumacher *et al*. showed no complications in any of their patients, including hydrocephalus, radionecrosis, or cystic tumor cavitation.[27] Boari denied malignant transformation and radiation-induced tumors occurred during follow-up.[5]

Limitations

It is plausible that several limitations might have influenced the results obtained. The first limitation was a small number of patients and a relatively short follow-up after radiosurgery. Inherent selection biases associated with nonrandomized treatment assignments were another flaw. Despite that, prospective data gave reasonable tumor control and cranial nerve function preservation rates compared to previously published reports. Another drawback was the loss of patients to follow-up over time. Patients' compliance at long-term follow-up was variable, particularly for patients living far from our center and the poor patients; this limitation could not be easily overcome, even by scheduling subsequent examinations at hospital discharge.

CONCLUSION

In this group of patients, RGK proved to be effective and safe in the management of VS mearing <3 cm. Tumor control throughout follow-up was comparable to other studies; no significant neurological complications were observed at long-term either. Further multicentric prospective studies with larger cohorts are warranted to validate the findings of this paper.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Agha RA, Sohrabi C, Mathew G, Franchi T, Kerwan A, O'Neill N, *et al*. The PROCESS 2020 guideline: Updating consensus preferred reporting of CasE series in surgery (PROCESS) guidelines. Int J Surg 2020;84:231-5.
2. Andrews DW, Suarez O, Goldman HW, Downes MB, Bednarz G, Corn BW, *et al*. Stereotactic radiosurgery and fractionated stereotactic radiotherapy for the treatment of acoustic schwannomas: Comparative observations of 125 patients treated at one institution. Int J Radiat Oncol Biol Phys 2001;50:1265-78.
3. Bailo M, Boari N, Franzin A, Gagliardi F, Spina A, del Vecchio A, *et al*. Gamma knife radiosurgery as primary treatment for large vestibular schwannomas: Clinical results at long-term follow-up in a series of 59 patients. World Neurosurg 2016;95:487-501.
4. Bailo M, Boari N, Gagliardi F, Franzin A, Piloni M, Spina A, *et al*. Gamma knife radiosurgery for residual and recurrent vestibular schwannomas after previous surgery: Clinical results in a series of 90 patients and review of the literature. World Neurosurg 2017;98:60-72.
5. Boari N, Bailo M, Gagliardi F, Franzin A, Gemma M, del Vecchio A, *et al*. Gamma Knife radiosurgery for vestibular schwannoma: Clinical results at long-term follow-up in a series of 379 patients. J Neurosurg 2014;121 Suppl:123-42.
6. Carratalá IL, García VE, Alborch MO, de Paula Vernetta C, Algarra JM. Radiosurgery as treatment for acoustic neuroma. Ten years' experience. Acta Otorrinolaringol (English Ed) 2014;65:327-31.
7. Coughlin AR, Willman TJ, Gubbels SP. Systematic review of hearing preservation after radiotherapy for vestibular schwannoma. Otol Neurotol 2018;39:273-83.
8. Flickinger JC, Lunsford LD, Linskey ME, Duma CM, Kondziolka D. Gamma knife radiosurgery for acoustic tumors: Multivariate analysis of four year results. Radiother Oncol 1993;27:91-8.
9. Goetsch SJ, Murphy BD, Schmidt R, Micka J, De Werd L, Chen Y, *et al*. Physics of rotating gamma systems for stereotactic radiosurgery. Int J Radiat Oncol Biol Phys 1999;43:689-96.
10. Haque R, Wojtasiewicz TJ, Gigante PR, Attiah MA, Huang B, Isaacson SR, *et al*. Efficacy of facial nerve-sparing approach in patients with vestibular schwannomas. J Neurosurg 2011;115:917-23.
11. Hasegawa T, Kida Y, Kato T, Iizuka H, Kuramitsu S, Yamamoto T. Long-term safety and efficacy of stereotactic radiosurgery for vestibular schwannomas: Evaluation of 440 patients more than 10 years after treatment with Gamma Knife surgery. J Neurosurg 2013;118:557-65.
12. Horiba A, Hayashi M, Chernov M, Kawamata T, Okada Y.

Hearing preservation after low-dose gamma knife radiosurgery of vestibular schwannomas. Neurol Med Chir (Tokyo) 2016;56:186-92.
13. Huang CW, Tu HT, Chuang CY, Chang CS, Chou HH, Lee MT, *et al*. Gamma Knife radiosurgery for large vestibular schwannomas greater than 3 cm in diameter. J Neurosurg 2018;128:1380-7.
14. Khrais T, Romano G, Sanna M. Nerve origin of vestibular schwannoma: A prospective study. J Laryngol Otol 2008;122:128-31.
15. Komatsuzaki A, Tsunoda A. Nerve origin of the acoustic neuroma. J Laryngol Otol 2001;115:376-9.
16. Kondziolka D, Lunsford LD, McLaughlin MR, Flickinger JC. Long-term outcomes after radiosurgery for acoustic neuromas. N Engl J Med 1998;339:1426-33.
17. Kondziolka D, Mousavi SH, Kano H, Flickinger JC, Lunsford LD. The newly diagnosed vestibular schwannoma: Radiosurgery, resection, or observation? Neurosurg Focus 2012;33:E8.
18. Kumon Y, Kohno S, Ohue S, Watanabe H, Inoue A, Iwata S, *et al*. Usefulness of endoscope-assisted microsurgery for removal of vestibular schwannomas. J Neurol Surg B Skull Base 2012;73:42-7.
19. Lipski SM, Hayashi M, Chernov M, Levivier M, Okada Y. Modern Gamma Knife radiosurgery of vestibular schwannomas: Treatment concept, volumetric tumor response, and functional results. Neurosurg Rev 2015;38:309-18.
20. Lunsford LD, Niranjan A, Flickinger JC, Maitz A, Kondziolka D. Radiosurgery of vestibular schwannomas: Summary of experience in 829 cases. J Neurosurg 2013;102 Suppl:195-9.
21. McClelland S, Guo H, Okuyemi KS. Morbidity and mortality following Acoustic neuroma excision in the United States: Analysis of racial disparities during a decade in the radiosurgery era. Neuro Oncol 2011;13:1252-9.
22. Murphy ES, Barnett GH, Vogelbaum MA, Neyman G, Stevens GH, Cohen BH, *et al*. Long-term outcomes of Gamma Knife radiosurgery in patients with vestibular schwannomas. J Neurosurg 2011;114432-40.
23. Nonaka Y, Fukushima T, Watanabe K, Friedman AH, Sampson JH, McElveen JT, *et al*. Contemporary surgical management of vestibular schwannomas: Analysis of complications and lessons learned over the past decade. Neurosurgery 2013;72(2 Suppl Operative):ons103-15; discussion ons115.
24. Régis J, Pellet W, Delsanti C, Dufour H, Roche PH, Thomassin JM, *et al*. Functional outcome after gamma knife surgery or microsurgery for vestibular schwannomas. J Neurosurg 2002;97:1091-100.
25. Régis J, Roche P, Delsanti C, Thomassin J, Ouaknine M, Gabert K, *et al*. Modern management of vestibular schwannomas. Prog Neurol Surg 2007;20:129-41.
26. Sarmiento JM, Patel S, Mukherjee D, Patil CG. Improving outcomes in patients with vestibular schwannomas: Microsurgery versus radiosurgery. J Neurosurg Sci 2013;57:23-44.
27. Schumacher AJ, Lall RR, Lall RR, Iii AN, Ayer A, Sejpal S, *et al*. Low-dose gamma knife radiosurgery for vestibular schwannomas: Tumor control and cranial nerve function preservation after 11 Gy. J Neurol Surgery, Part B Skull Base 2017;78:2-10.
28. Smith DR, Saadatmand HJ, Wu CC, Black PJ, Wuu YR, Lesser J, *et al*. Treatment outcomes and dose rate effects following gamma knife stereotactic radiosurgery for vestibular schwannomas. Clin Neurosurg 2019;85:E1084-94.
29. Wangerid T, Bartek J, Svensson M, Förander P. Long-term quality of life and tumour control following gamma knife radiosurgery for vestibular schwannoma. Acta Neurochir (Wien) 2014;156:389-96.

How to cite this article: Kieu HD, Vuong DN, Mai KT, Pham PC, Le TD. Long-term outcomes of rotating gamma knife for vestibular schwannoma: A 4-year prospective longitudinal study of 89 consecutive patients in Vietnam. Surg Neurol Int 2021;12:585.