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Original Research Article

Efficacy and Toxicity of Stereotactic Radiotherapy Using CyberKnife in Patients of Vestibular Schwannoma: A Single Institutional Study

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Abstract: *Vestibular schwannoma (VS) is a benign tumor arising from the vestibulocochlear nerve, with management options ranging from microsurgical resection to stereotactic radiotherapy (SRT). CyberKnife (CK) offers frameless, image-guided stereotactic radiosurgery (SRS) or fractionated stereotactic radiotherapy (FSRT), providing conformal target coverage while minimizing toxicity to adjacent organs at risk (OAR).* ***Objective:*** *To evaluate the efficacy and toxicity of CK based SRS/SRT in VS via radiological response on MRI, symptom change (at 3,6 and 12 months interval), and OAR dosimetry at a single institution.* ***Methods:*** *This prospective observational study included 37 consecutive patients with radiologically or histopathologically confirmed VS treated with CK between December 2023 and December 2024. Baseline demographics, tumor characteristics, and treatment parameters were recorded. SRS was delivered in single fractions of 13–15 Gy, while FSRT was delivered in 3 fractions (21 Gy) or five fractions (20–22.5 Gy). Dosimetric parameters were assessed in accordance with the 2022 UK consensus guidelines. The primary endpoint was radiological tumor response at 6 and 12 months, assessed by MRI. Secondary endpoints included changes in presenting symptoms (hearing loss, headache, vertigo, tinnitus) and OAR dosimetry. Symptom improvement was analyzed using paired significance tests with $\alpha = 0.05$.* ***Results:*** *The median age was 52 years (range 19–77), with a female predominance (64.8%). Laterality was left in 54.0%, right in 43.2%, and bilateral in one case. Mean tumor volume was 19.8 cm³ (range 0.53–73.9). Histopathological confirmation was available in 24.3% of cases. OAR analysis showed D0.035 cc (Dose to 0.035cc) to the brainstem of 7.2-9.9Gy for SRS and 19.8 ± 6.32Gy for FSRT and a mean ipsilateral cochlear dose of 2.8-3.7Gy for SRS and 14.29 ± 7.36 Gy for FSRT. At 6 and 12 months, no progressive disease was observed; stable disease was reported in 81.1% and 67.5% of patients, while partial responses were seen in 18.9% and 32.4%, respectively. A complete response was not achieved during the follow-up period. Composite symptom improvement was statistically significant ($p = 0.0035$).* ***Conclusion:*** *CK-based SRS/FSRT provided excellent early radiological control of VS with no progression at 12 months and significant improvement in symptoms, even in patients with relatively large baseline tumor volumes. Treatment was delivered within safe OAR dose limits, supporting CK as an effective modality for both short-term and long-term disease control. Extended follow-up is warranted to assess hearing preservation and long-term tumor control across fractionation schedules.*

Keywords: vestibular schwannoma; acoustic neuroma; CyberKnife; stereotactic radiosurgery; hypofractionated stereotactic radiotherapy; organs at risk; cochlea; brainstem; tumor control; toxicity

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Introduction

Vestibular schwannoma (VS) is a benign cerebellopontine-angle tumor in which treatment aims to balance durable tumor control against cochlear and cranial-nerve toxicity. Contemporary stereotactic approaches include single-session stereotactic radiosurgery (SRS) and hypofractionated stereotactic radiotherapy (SRT), typically administered in 3–5 fractions, using platforms such as CyberKnife (CK) (1–3). CK-based hypofractionation (e.g., 3×7 Gy or 5×5 Gy) offers submillimetric tracking and steep gradients that may benefit hearing and facial/trigeminal nerve preservation while maintaining high local control (LC) (1).

Across the modern CK series, LC commonly exceeds 90–96% at 3–5 years of age. A single-center CK-HSRT cohort (n=82; 3×7 Gy/5×5 Gy) reported 96.3% LC with only two mild late facial palsies and serviceable-hearing preservation (HP) of 46% at ~4 years (1). A CK fractionated series (median three fractions; n=119) showed actuarial LC 96%, 94%, and 88% at 1, 3, and 5–7 years, respectively; serviceable HP 59%; and House–Brackmann (HB) > three facial dysfunction in 2% (4). A three-weekly-fraction CK regimen (total 21 Gy) achieved crude LC 86% at ~4 years, with 95.5% free of complications; late trigeminal toxicity occurred in one patient, and 5-year Kaplan–Meier HP was 17.5% (illustrating heterogeneity across fractionation/dosimetry and selection) (5). A five-fraction HSRT series reported LC ~95–96% at 5–7 years with HP ~60% and low cranial-nerve morbidity (facial ≤~2–4%, trigeminal ≤~3%) (6,7).

Systematic syntheses concur: narrative and meta-analytic reviews place LC >90% for lesions <3 Cm, with mid-term HP ~60–70% and low facial/trigeminal neuropathy rates (≈1–5%) (2,3,8–10). Dose-de-escalation (e.g., 12–13 Gy single-fraction equivalents) preserves high LC (5–10 y PFS ~92–98%) while reducing toxicity (11)

Device-agnostic SRS meta-analyses with long follow-up (median 6.7 years; n≈1400) report pooled HP 59.4%, LC 96.1%, facial nerve deficit 1.3%, trigeminal neuropathy 3.2%; prognosticators for hearing include younger age, better baseline hearing, smaller volume, and lower cochlear dose (9). A 2024 network meta-analysis suggested that SRS and fractionated regimens outperform observation for LC, with SRS often ranking favorably for facial/trigeminal preservation. Among fractionations, the 5-fraction FSRT showed promising hearing ranks in indirect comparisons (10). Importantly, the first randomized trial (ACOUNEU, 2025) did not demonstrate superiority of hypofractionation over single-session SRS for hearing preservation, supporting individualized selection rather than a one-size-fits-all approach (14). Small single-institution CK studies report high LC (often ~95–100%), HP of ~50–75% when the baseline is serviceable, and very low high-grade cranial-nerve toxicity (12). Overall, CK-SRT provides durable control with low toxicity; however, hearing outcomes vary depending on baseline status, tumor size/Koos grade, fractionation/dose, and cochlear constraints (1–3, 8–11). This study aims to assess the efficacy and toxicity

of stereotactic radiotherapy (SRS/FSRT) using CyberKnife in patients with Vestibular Schwannoma (VS).

Methodology

We conducted a prospective observational study at the Atomic Energy Cancer Hospital–NORI (AECH-NORI), Islamabad, including 37 patients diagnosed with vestibular schwannoma (VS) between December 2023 and December 2024. Eligible participants were adults aged 18 years or older with an Eastern Cooperative Oncology Group (ECOG) performance status of 0 or 1. Diagnosis was confirmed either histopathologically or radiologically using magnetic resonance imaging (MRI). Patients with prior cranial irradiation, concurrent malignancies, or a poor performance status (ECOG > 1) were excluded from the study.

All patients received CyberKnife stereotactic radiotherapy treatment. Treatment planning involved 1mm thin-sliced contrast-enhanced MRI fused with CT simulation to ensure precise target delineation and accurate treatment planning. Dosimetric parameters, including conformity index, homogeneity index, and dose to organs at risk (OARs), were carefully evaluated for each case.

Follow-up assessments were conducted using contrast-enhanced MRI at 3, 6, and 12 months post-treatment as well as by evaluating symptom change. Local tumor control was defined as either stable disease or a reduction in tumor volume based on standardized volumetric criteria. Treatment-related toxicity was evaluated by monitoring for neurological adverse effects at each follow-up visit, and events were graded according to the Common Terminology Criteria for Adverse Events (CTCAE), version 5.0.

Hearing function was assessed with pure-tone audiometry performed at baseline and during follow-up visits. Hearing status was classified according to the Gardner–Robertson (GR) Hearing Scale. Descriptive statistics were used to summarize demographic and clinical characteristics, while paired statistical tests were applied to compare pre- and post-treatment hearing outcomes and symptom changes. A p-value of less than 0.05 was considered statistically significant.

Results

Among 37 patients, the median age was 52 years (range 19-77years) with a female dominance of 64.8% (24). Regarding laterality, it was observed that left-sided tumors (54%) were more frequent than right-sided tumors (43.2%), with one patient having bilateral disease. Only 9 (24.3%) patients had a histopathological diagnosis, while the rest were diagnosed based on imaging (Table 1). The main symptoms were hearing impairment, headache, vertigo, and tinnitus. The mean tumor volume was 19.8 cm^3, ranging from 0.53 cm^3 to 73.9 cm^3. The dose range used for stereotactic radiosurgery (SRS) was 13-15Gy with a mean of 13.7 ± 1.38 While the dose range used for fractionated stereotactic radiotherapy (FSRT) was 20-22.5 Gy in 5 fractions, with a mean of 22.35 ± 0.5 Gy. For three fractions SRT, the prescribed dose was 21Gy. Among the organs at risk doses, the mean dose to 0.035 cc of the brainstem was 7.2-9.9Gy in SRS and 19.8 ± 6.32 Gy in FSRT, while the mean dose to the ipsilateral cochlea was 2.8-3.7Gy in SRS and 14.29 ± 7.36 Gy in FSRT (doses according to the UK consensus guidelines of 2022). There was a statistically significant improvement in symptoms, with a p-value of 0.0035, suggesting a positive response to stereotactic radiotherapy. However, the radiological outcomes at 6 and 12 months showed stable disease in 30 (81.1%) and 25 (67.5%) patients, respectively, while partial disease was observed in 7 (18.9%) and 12 (32.4%) patients at 6- and 12-month intervals, respectively. It is noteworthy that although most patients had stable disease, the visible necrosis (as shown in Fig. 2) inside the tumor, as well as the decreased contrast enhancement, is evidence of a response and supports symptomatic improvement. None of the patients developed progressive disease or a complete response. The hearing response was assessed at 6 and 12 months using pure tone audiometry, showing improvement in 18.9% (7) and 29.7% (11) of patients, respectively. It is worth noting that patients who did not show hearing improvement already had permanent damage to the nerve fibers. Similarly, significant improvement in other symptoms was seen as well (mentioned in Table 2)

Table 1: Patient characteristics and Disease features

Parameters	Percentages
Gender	
Male	35.2%
Female	64.8%
Performance status	
ECOG 0	8%
ECOG 1	91.8%
Diagnosis	
Histopathological	24.3%
Radiological	75.7%
Laterality	
Left	54%
Right	43.2%
Bilateral	2.8%
Presenting Symptoms	
Hearing Impairment	79.8%
Vertigo	47.2%
Headache	39.4%

Table 2: Treatment, doses, and results

Parameters	**Percentages**			
No of SRS	16.3%			
No of FSRT*	83.7%			
Dose range	***SRS***		***FSRT****	
Tumor Dose	13-15Gy		20-22.5Gy, 3-5 fx	
Brainstem dose (0.035cc)	7.2-9.9Gy		19.8 ± 6.32	
Ipsilateral Cochlea dose (D_{mean})	2.8-3.7Gy		14.29 ± 7.36	
Radiological Response	***Complete response***	***Partial Response***	***Stable Disease***	***Progressive Disease***
3 months	None	None	100%	None
6 months	None	18.9%	81%	None
12months	None	32.4%	67.5%	None
Symptoms Improvement (1year after SRT)	***Hearing***	***Vertigo***	***Headache***	
	29.7%	61.5%	64.8%	

**Fractionated Stereotactic Radiotherapy , fx = fraction, SRT= Stereotactic Radiotherapy*

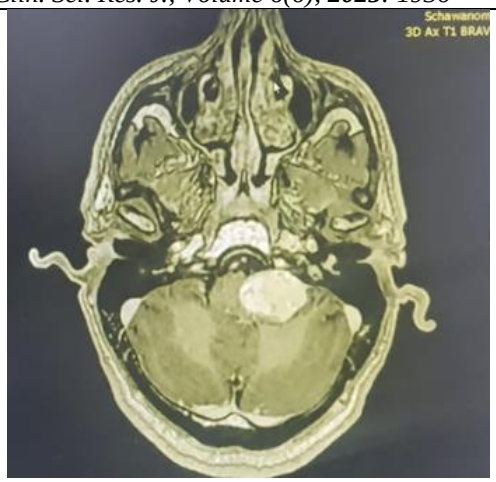

Figure 1: Pre-Treatment image

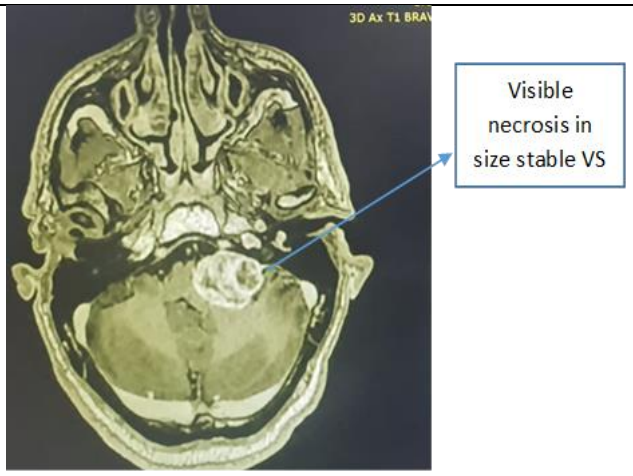

Figure 1: Post-Treatment image

Discussion

In this single-institution CyberKnife series (n = 37), patients were middle-aged (median, 52 years) with a female predominance, mixed SRS/FSRT prescriptions (13–15 Gy single fraction; 21 Gy/3 fractions; 20–22.5 Gy/5 fractions), and relatively large tumors (mean, 19.8 cm^3). At 6 months, radiology showed no progression (81% stable, 18.9% partial response), and there was a statistically significant improvement in global symptoms ($p = 0.0035$). These findings are broadly consistent with contemporary radiosurgical literature, although they are limited by the short follow-up period and substantial baseline tumor volumes.

Local control after modern SRS/FSRT for vestibular schwannoma (VS) typically exceeds 90–97% at 3–5 years across techniques and platforms, with commonly used schedules of 12–13 Gy SRS, 18 Gy/3 fx, or 25–30 Gy/5 fx (16). Dose de-escalation to 12–13 Gy preserves high control with lower cranial-nerve toxicity in many reports and reviews (17). Against that backdrop, our mixed-regimen prescriptions fall within accepted ranges—our SRS upper bound (15 Gy) is higher than current "low-dose" norms, whereas 22–22.5 Gy/5 fractions is at the conservative end of 5-fraction practice but has been used in selected series of larger lesions (16, 17, 19). The absence of early progression in our cohort aligns with typical early post-treatment trajectories, where stable or modestly regressing volumes predominate at 6–12 months, and overt progression is uncommon at this early stage (16,19–21). Moreover, transient treatment-related pseudoprogression is well described, often peaking around 6–18 months, and can mimic early growth; therefore, extended surveillance is essential before labeling failure (20, 21).

Clinically, our symptom improvement signal aligns with reports that many patients experience stabilization or improvement of vestibular/cranial nerve symptoms after radiosurgery. However, series differ in how composite symptom endpoints are defined (17). For example, cohorts treated with reduced-dose SRS reported that nearly half of the patients showed improvement, and most of the remainder remained stable on clinical metrics, with low-grade toxicity (1–2) (17). That heterogeneity reinforces the importance of clear, prospectively defined symptom scales in future work.

Hearing preservation (HP) remains the most common variable outcome across studies. A long-term meta-analysis reveals an overall HP rate of ~60% with multi-year follow-up, which is strongly dependent on baseline hearing, tumor size/volume, and cochlear dose (18). Our series includes audiometric outcomes at 12 months showing response in those having serviceable hearing at baseline although mean tumor volume was~20 cm^3. However, the literature would predict lower HP probabilities than in small-volume cohorts and would favor fractionation and cochlear dose minimization when serviceable hearing exists (16,18). Contemporary evidence and guidance converge on aiming for mean cochlear doses <4 Gy with single-fraction SRS, with correspondingly higher allowable means for hypofractionation, recognizing the steep correlation between cochlear dose metrics and hearing loss (22–24, 27–29). Our reporting of brainstem D0.035 cc and mean cochlear dose is consistent with current UK consensus practice for CNS OARs (near-max reported to 0.035 cc and mean constraints for the cochlea), supporting the safety framework used in this cohort (26).

Finally, emerging comparative evidence continues to nuance technique selection. Reviews emphasize that both single-fraction SRS and hypofractionated SRT achieve high control with low cranial-nerve morbidity, while HP advantages are inconsistent across regimens and strongly patient-/tumor-specific (16, 18, 26). A recent randomized trial comparing hypofractionation with single-session SRS did not demonstrate superiority for hearing preservation, underscoring individualized planning (tumor size, baseline hearing, and cochlear constraints) rather than one-size-fits-all fractionation (25).

Overall, our early outcomes—no radiologic progression at 6 and 12 months and significant symptom improvement—fit well within the expected early-term profile reported in modern CK series. With ongoing follow-up of 24–36 months, we anticipate durable radiologic control rates comparable to those published in the literature. Definitive conclusions about hearing and late cranial-nerve toxicity will require the longer horizon emphasized in recent syntheses (16–18, 20, 21, 26).

Conclusion

Both SRS and FSRT are non-invasive treatments with over 90% tumor control rates, making them highly effective options for managing vestibular schwannoma. Their success in halting tumor progression offers a favorable alternative to more invasive surgery, especially for patients where preservation of neurological function and quality of life are priorities. Typically, SRS is favored for smaller tumors due to its precise, single-dose delivery, while FSRT is considered for larger lesions because fractionation can better spare surrounding tissues. However, without randomized studies directly comparing them, this preference remains based on clinical experience and dosing principles rather than definitive evidence.

Declarations sh

Data Availability statement

All data generated or analysed during the study are included in the manuscript.

Ethics approval and consent to participate

Approved by the department concerned. (IRBEC-24)

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Approved
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Conflict of interest

The authors declared the absence of a conflict of interest.

Author Contribution

SMS (**RMO**)
Manuscript drafting, Study Design,
Review of Literature, Data entry, Data analysis, and drafting an article.
HM (Associate Professor)
Conception of Study, Development of Research Methodology Design, Study Design, manuscript review, and critical input.

All authors reviewed the results and approved the final version of the manuscript. They are also accountable for the integrity of the study.

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