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Chapter 4

Vestibular Schwannoma: Microsurgery or Radiosurgery

Ahmed Rizk

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Abstract

A vestibular schwannoma (VS) is a benign tumor that arises from the neurilemmal sheath of the vestibular nerve. VSs make up to 6–8% of all intracranial tumors and 70–80% of all cerebellopontine angle tumors. Three therapeutic options are currently considered for VS: expectant treatment, microsurgical resection, and radiosurgery. No class I evidence exists to support one treatment over the others, and some clinical aspects are usually taken into consideration in the decision-making process. Very few comparative studies published so far have addressed the clinical aspects supporting any one treatment modality. The pathology, diagnosis and treatment of VS are discussed in this chapter. Moreover, we aim in this chapter to discuss the results of the most recent clinical studies performed on different treatment strategies for VS. In addition, the results of the comparative studies between microsurgical and radiosurgical treatments for VS are discussed.

Keywords: vestibular schwannoma, radiosurgery, microsurgery, Gamma Knife, intraoperative neurophysiological monitoring, hearing preservation, facial nerve preservation

1. Introduction

Vestibular schwannomas (VS) are benign tumors that typically occur in the internal auditory canal (IAC) and in the cerebellopontine angle (CPA). They originate from Schwann cells of the vestibular nerve. The vestibular nerves are enclosed by central glial and peripheral neurilemmal sheaths. The VS arises from the distal sheath at or close to the neuroglial-neurilemmal junction (Obersteiner-Redlich zone). The transition zone is encountered 1 cm away from the brainstem, commonly occurring at or close to the internal auditory canal (IAC) [1]. VS arises from either the inferior [2, 3] or superior [4] vestibular nerve.

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The annual incidence is estimated to be between 0.5 and 1.7 per 100,000 persons, and the incidence is increasing with the widespread use of magnetic resonance imaging (MRI) [5]. VS represents 6–8% of all intracranial tumors and >80% of CPA tumor [6]. It occurs in equal frequency in adult males and females [7–9]. They typically occur between the fourth to sixth decades of life [10]. In teenagers, VSs have been rarely diagnosed [11], and in these cases, the tumor is usually associated with neurofibromatosis type II (NF2) [5]. Patients with NF2 often develop bilateral VS, which is sufficient to make the diagnosis of the disease. These tumors have different biological and clinical characteristics and must be differentiated from the unilateral spontaneous VS [12, 13].

The classical clinical presentation includes high-frequency sensorineural hearing loss, tinnitus, and vertigo. Three therapeutic options are currently considered for VS: expectant treatment, microsurgical resection, and radiosurgery. No class I evidence exists to support one treatment over the others, and some clinical aspects are usually taken into consideration in the decision-making process.

2. Diagnosis

The clinical presentation of VS may vary broadly depending upon tumor extension; whereas intrameatal tumors often present with high-frequency sensorineural hearing loss (about 90% of VS patients), tinnitus (65–75%), vestibular nerve dysfunction which includes vertigo, dizziness, and unsteadiness (in up to 61%); extrameatal tumors may also present with headache, facial hypoesthesia, facial weakness (4–8%), ataxia, lower cranial nerve damage, or hydrocephalus [14]. Another factor affecting clinical presentation is the site of origin of the tumor. Hearing is significantly better preserved in patients affected by medially arising VSs than in patients with laterally arising tumors [15]. The symptoms in VS progress slowly; however, it was noticed that sudden deterioration of symptoms may occur especially in cases of cystic tumors and usually represents intratumoral hemorrhage [16, 17].

A high degree of clinical suspicion is the best key for prompt diagnosis of VS. The clinician should be aware of VS diagnosis in patients complaining of unilateral hearing loss, tinnitus, and vertigo in any combination [7]. Patients with these complaints should undergo pure tone audiometry (PTA) and vestibular testing. Those with abnormalities on either, especially unilateral sensorineural hearing loss, should have MRI with and without contrast.

2.1. Hearing classification

Full audiometric assessment including pure tone audiometry (PTA) and speech discrimination score (SDS) should be done in cases of VS. In PTA, the mean hearing loss (in decibel "dB") at frequencies between 500 and 3000 Hz is assessed. SDS represents the percent of correct score when words are presented at a specified level above the speech recognition threshold. The Committee on Hearing and Equilibrium of the American Academy of Otolaryngology-Head Neck Surgery (AAO-HNS) published guidelines in 1995 for the

evaluation of hearing in VS. Accordingly, hearing level is classified into four classes [18], in which Classes A and B represent functional/serviceable hearing, whereas hearing Classes C and D are nonfunctional/nonserviceable (**Table 1**).

2.2. Facial function

Although facial nerve weakness is a rare presentation of VS patients, transient or even permanent facial palsy may occur in VS patients after treatment. Therefore, it is important to have a systematic classification of the facial nerve function. The House-Brackmann facial nerve grading system (HBGS) [19] was introduced in 1983 and endorsed by the Facial Nerve Disorders Committee of the American Academy of Otolaryngology-Head and Neck Surgery in 1984 as the standard for reporting facial nerve function (**Table 2**).

2.3. Radiological diagnosis

MRI is now the gold standard for VS diagnosis. High-field MRI (1.5–3 T) should be done, the examination protocol should include fluid attenuated inversion recovery (FLAIR), high-resolution 2D/3D T1-weighted sequences (e.g., T1-W Spin-Echo (SE) or Turbo-Spin-Echo-S (TSE)-Sequence) with and without intravenously administered contrast agent (0.2 ml/kg body weight Gadolinium DTPA), and high-resolution 3D T2-weighted sequences (e.g., CISS = constructive interference in a steady state, FIESTA-C = fast imaging employing steady state, etc.) with a film thickness of ≤1 mm isotrope [6]. Tumors as small as 2–3 mm may be diagnosed using MRI1. VS is usually isointense on T1-weighted images, hyperintense on T2-weighted

Hearing grade	Hearing loss in PTA	SDS (%)
Class A	≤30 dB	≥70
Class B	>30 to ≤50 dB	≥50
Class C	>50 dB	≥50
Class D	Any level	<50

Table 1. AAO-HNS hearing classification system.

Grade	Description
I	Normal function in all facial muscles
II	Slight weakness noticeable only on close inspection; complete eye closure
III	Obvious but not disfiguring difference between two sides; forehead shows slight-to-moderate movement; complete eye closure with effort
IV	Disfiguring asymmetry; no forehead movement; incomplete eye closure
V	slightly perceptible motion
VI	Complete paralysis

Table 2. House-Brackmann facial nerve grading system.

images, and enhances uniformly after contrast injection. Heterogeneous contrast enhancement or cystic degeneration may be found.

VS typically produces changes in the internal auditory canal (IAC), ranging from widening to destruction of the canal. However, normal IAC has been described in up to 10% of VS [20]. We measured the IAC in bone-window CT scan of 140 cases presented with unilateral VS, and we stratified the tumors into soft and firm varieties according to the intraoperative findings, the results showed that firm tumors were associated with significantly more widening of the IAC than soft tumors [21].

2.4. Tumor grading

The grading of VS depends on both tumor size and tumor extension. Different classification systems are available in the literature. Both Koos [22] and Hannover [23] classification systems classify VS into four grades according to the degree of tumor extension, which is an indicator of tumor size. According to Hannover classification, patients are classified regarding tumor extension as follows: T1, purely intrameatal; T2, intra- and extrameatal; T3a, filling the cerebellopontine cistern; T3b, reaching the brainstem; T4a, compressing the brainstem; and T4b, severely dislocating the brainstem and compressing the fourth ventricle.

3. Treatment options

Three management options are provided for VS patients: observation, radiosurgery, and surgery. The concept behind treatment of VS has been widely changed in the last two decades. Before the widespread of radiosurgery, VS treatment was based on microsurgery (MS) with the aim of complete tumor removal to avoid recurrence. With the development of radiosurgery (RS), it could be possible to stop the growth of the tumor with minimal side effects and with a very high level of preservation of nerve functions; therefore, nowadays, preservation of function is a primary aim in VS treatment. However, it is important to remember that preservation of function is sometimes possible after surgery and at the same time, tumor could be completely removed. On the other hand, failure of tumor control (recurrence) may occur after surgery as well as after radiosurgery; also, combined treatment is not always successful. Other than preservation of function, the complaints of the patient play an important role in the treatment decision because if a patient gets a functional preservation treatment and still complaining of tinnitus or vertigo, this may be more disabling to him/her. Therefore, the choice of the treatment option for each VS patient should be based on an individualized concept [5].

3.1. Observation (wait and scan)

Before discussing the conservative strategy for treatment of VS, it is important to know the natural history of the disease. The average growth rate in VS is 2–2.5 mm/year [24]. Neurofibromatosis type II-associated vestibular schwannomas tend to be more aggressive, with an increased average growth rate of 4 mm per year [25]. Intrameatal tumors seem to have lower growth rates than extrameatal lesions, and a younger age is associated with a more rapid tumor growth.

More recently, an extensive research has been done on the natural history of VS, and it was found that there is a group of VS tumors that grows very slowly or even does not grow at all, and even hearing preservation is sometimes maintained [26]. A study was performed on the natural history of VS less than 2 cm has showed that only 17% of the intrameatal and 28.9% of the extrameatal tumors grew; it was also found that this growth exclusively occurred within 5 years of diagnosis [27]. Sughrue et al. performed a meta-analysis on conservative treatment (982 patients) and found better hearing preservation in patients with yearly tumor growth rate less than 2.5 mm (75 vs. 32%) [28].

Therefore, it is widely accepted that newly diagnosed asymptomatic VS could be considered for initial wait and scan strategy. Regular clinical and radiological examination should be performed, and active treatment is recommended in cases of significant tumor growth (more than 2 mm increase in the largest tumor diameter) [27].

3.2. Stereotactic radiosurgery

3.2.1. Techniques

Radiosurgery is a radiation procedure using converging, narrow ionizing beams, stereotactically focused on an intracranial predetermined target volume, in order to induce biological arrest or destructive effects within this volume with minimal irradiation of the surrounding tissues. The modalities currently used in stereotactic radiosurgery include either photon devices such as Gamma Knife (GK) and modified linear accelerators (LINAC) or proton and heavy-ion charged particles generated by a cyclotron or synchrotron [29].

3.2.1.1. Gamma Knife

Gamma Knife consists of a thick cast, hemispherical steel shell containing a dome-shaped core of 201 cylindrical Co-60 sources, all being radially aligned toward a common focal point situated at a distance of 40 cm [29]. During treatment, the patient's head is fixed to the stereotactic frame. Ideally, the frame is placed such that the lesion to be treated is located as close to the frame center as possible. Following frame application, imaging is performed (usually MRI), and the images are interfaced with a computer software treatment planning system. Radiosurgical dose planning is the most critical aspect of the procedure, and preservation of cochlear and facial nerve function is the main concern during planning. For moderate-sized tumors, preservation of brainstem function is also a consideration. The 50% isodose line where radiation dose is half of the central dose is usually serving as the margin isodose. With the application of recent Gamma Knife models like Leksell Gamma Knife Perfexion and Model C lead to greater improvements in precise dose planning and hence the application of lower radiation dose to the tumor periphery has been available. Currently, 13 Gy is recommended as the tumor margin dose; this dose is associated with reduced complications and yet maintains a high rate of tumor control [30].

3.2.1.2. Linear accelerator (LINAC) and CyberKnife

LINAC uses high-energy electromagnetic waves to accelerate electrons to high energy through a microwave structure. When the electron strikes a target, X-rays are produced. Like Gamma Knife, LINAC is based on using a stereotactic frame for lesion localization, treatment set-up,

and patient immobilization during the treatment [29, 31]. The primary advantage of LINAC over Gamma Knife and cyclotron-based methods is the lower cost of installation. Other advantages include great flexibility in photon delivery, lack of a field size limitation, and the possibility of fractionation. Disadvantages include longer treatment times, especially for complex-shaped lesions [32].

CyberKnife has been developed using image guidance instead of an external frame. It combines a lightweight LINAC designed for radiosurgery and mounted to a robotic manipulator, which can position and point the LINAC. The advantages of CyberKnife include easier fractionation, the ability to treat young patients without general anesthesia, and the flexibility to treat lesions throughout the body [32].

3.2.1.3. Heavy particle radiosurgery

Heavy particles (e.g., protons, helium, carbon nuclei) involve very expensive technologies (cyclotrons and synchrocyclotrons) which are available at only few centers around the world. In contrast to the photon radiation seen with gamma and X-rays, heavy particle radiation is more conformal due to Bragg peak effect. This occurs because heavy particles deposit energy at the end of their target with little falloff of radiation to nearby structures. This phenomenon makes it easier to give efficient conformal radiation treatment to large tumors [33].

3.2.2. Radiosurgery results

The ultimate goals of radiosurgery for VS include control of tumor growth and, ideally, tumor shrinkage (**Figures 1** and **2**) while preserving functionality of the vestibulocochlear nerve and the surrounding cranial nerves and quality of life.

During the early period following radiosurgery, transient tumor growth may occur, usually between 6 and 24 months after radiation. In large tumors, however, compression-related symptoms may occur due to the initial expansion, and surgical treatment may be required [34]. In addition, cystic tumors may display sudden and dramatic growth; therefore, these tumors may not be eligible for radiosurgery, and primary surgery is recommended [27].

Van Eck and Horstmann introduced two entities of tumor control after Gamma Knife radiosurgery for VS: "MRI-based tumor control" was used in cases of no increase, or increase of less than 10% of the initial tumor volume at follow-up, while "clinical tumor control" was used when clinical symptoms did not progress, and no further treatment was necessary. They reported MRI-based tumor control rate of 87% and clinical control rate of 97.5% after a mean follow-up duration of 22 months [35]. Recently, the marginal radiation dose was reduced in order to avoid cranial nerve complications; therefore, more data are needed regarding long-term rates of tumor control after radiosurgery after using these new regimens. Even in cases where the tumor remained stable for 3 years after treatment, delayed tumor growth may occur [36].

Reviewing the literature on radiosurgery for VS, it is important to remember that recent studies may show better results due to advances in radiosurgery treatment with the use of high-resolution MRI and recent treatment planning software. Other factors that should be critically looked after when reviewing the literature are the definition of tumor control, the

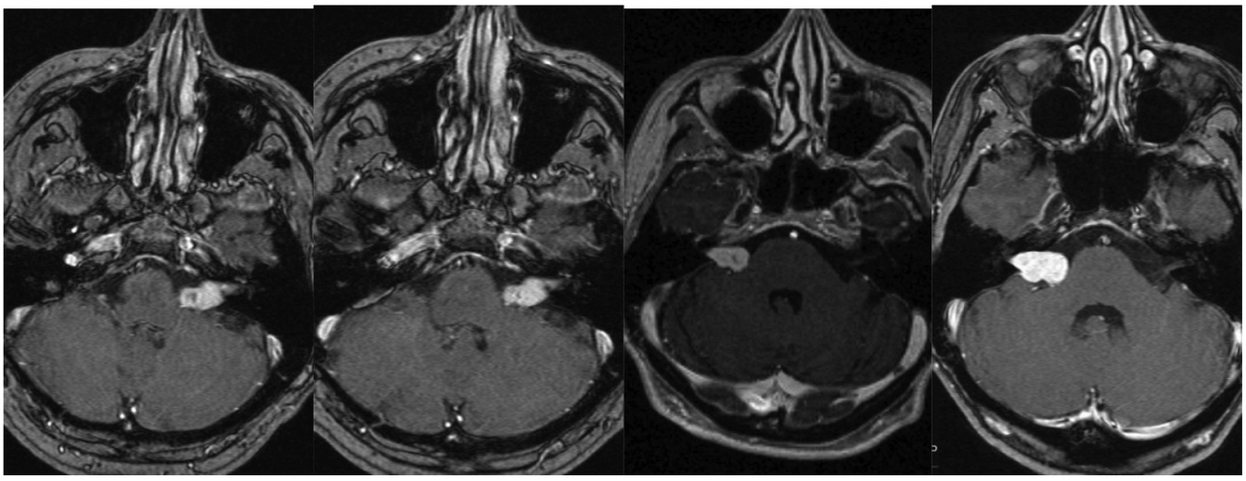

Figure 1. Axial MRI (T1-with contrast) of two cases of VS treated with Gamma Knife radiosurgery (13 Gy marginal dose) with follow-up MRI showed good tumor control after 15 months (case on the left side) and after 29 months (case on the right side).

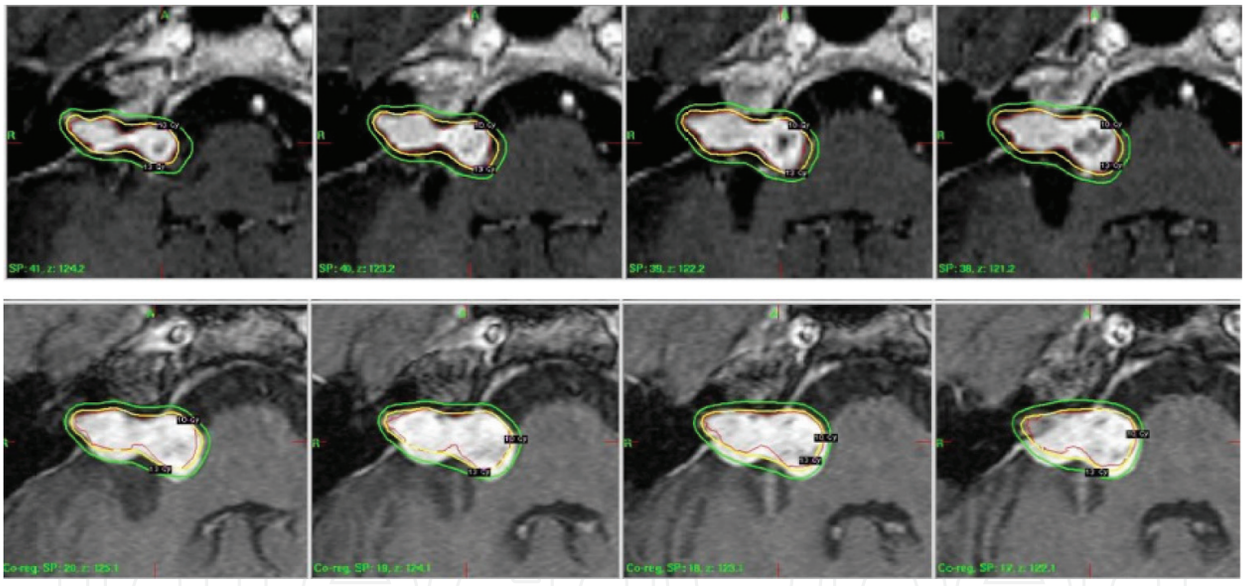

Figure 2. Axial MRI (T1-with contrast) of a VS case treated with Gamma Knife radiosurgery (13 Gy marginal dose) with follow-up MRI after 21 months (lower row) showed increase in tumor volume in comparison with the tumor volume before treatment (upper row).

duration follow-up, as well as the tumor size before treatment. In the radiosurgical literature, tumor size is usually reported in volume rather than in diameter as in the surgery literature [37].

In a meta-analysis included 3233 VS patients treated with Gamma Knife between 2007 and 2011 with an average marginal dose of 12.4 Gy and a mean follow-up of 51 months, Rykaczewski and Zabek reported tumor growth control in 92.7% and preservation of functional hearing in 66.4% of patients [30].

In another meta-analysis performed on Gamma Knife treated cases where tumors less than 4 cm were included and a mean follow-up of 2 years, the hearing preservation rate was 44% and tumor control rate was 91% [38].

The results of radiosurgery for VS are better in small tumors. A recent meta-analysis was conducted on tumors less than 2 cm treated by radiosurgery with follow-up more than 5 years and reported hearing preservation rate of 70.2% and a tumor control rate of 96.2%. They reported facial neuropathy rates using GK between 0 and 1.8% per study, while the rates of trigeminal neuropathy ranged between 0 and 3.1% per study. Interestingly, the rate of facial neuropathy in one study on LINAC was 6.9% [39].

It is important to note that a recent meta-analysis on CyberKnife for VS included 800 patients studied during 1998 and 2012 showed results similar to that of GK. The meta-analysis revealed the collective mean tumor control rate to be 96.3%. The collective hearing preservation rate was 79.1% in 427 patients with measurable hearing. The trigeminal neuropathy rate was 2.0%, facial neuropathy rate was 2.0%, and cerebellar/brainstem toxicity rate was 1.8% [26].

Maducdoc et al. performed a thorough literature review on malignant transformation of VS, they included only cases of histopathologic evidence of malignant transformation. They reported 11 cases of malignant transformation after radiosurgery, 4 cases after microsurgery, and 18 cases of either primary malignant VS or de novo transformation to malignancy without surgical intervention of any type. Therefore, it remains possible that the malignant transformation is part of the natural history of rare unfortunate event. In addition, they identified 12 cases of radiation-associated malignant tumors in the setting of NF2 and concluded that radiosurgery of NF2 tumors has been associated with a higher likelihood of malignant transformation [40]. Follow-up should be conducted for 5–20 years following radiation in order to detect any radiation-associated tumors that may develop.

3.3. Surgery

3.3.1. Surgical approaches

Three surgical approaches are available for VS removal: retrosigmoid, translabyrinthine, and middle fossa. The translabyrinthine and the retrosigmoid approaches can be used for all tumor sizes, whereas the middle fossa approach is useful only for removal of small tumors. Hearing preservation can be achieved only through the retrosigmoid or middle fossa approaches. The risk implied for patients is minimized if the surgeon and the team use the approach with which they are most familiar [23].

The middle fossa approach is suitable for intrameatal tumors and also for small tumors (less than 20 mm) with slight extrameatal extension. It is a subtemporal extradural approach that allows drilling of the roof of the internal auditory canal (IAC) and hence, removal of an intrameatal VS is possible. Retraction of the temporal lobe may be associated with the risk of seizures or sometimes temporal lobe contusion and hence neurological dysfunction [41]. When drilling into the IAC from above, the facial nerve has to be manipulated before reaching the tumor, and therefore, the facial nerve preservation results are inferior to those following other approaches [5, 42].

The translabyrinthine approach is the most widely used approach for removal of VS by neuro-otologists. This approach is hearing destructive, by definition, so it is suitable in cases of nonfunctional hearing. It is a direct approach to the IAC through drilling the mastoid air cells, and the labyrinth. It offers removal of VS of any size, as it provides wide access to the facial nerve and the contents of the CPA with minimal retraction of the cerebellum [41].

In the retrosigmoid approach, the cerebellopontine angle (CPA) is approached after retraction of the cerebellum and hence large VS extending into the CPA could be safely removed. The approach allows wide exposure of the CPA and decompression of the brainstem as well as the cranial nerves; from the trigeminal till the lower cranial nerves. Opening of the posterior wall of the IAC allows for removal of intracanalicular VS. Wide opening of the posterior wall IAC may result in violation of the posterior semicircular canal or the endolymphatic sac and therefore, may be critical for hearing preservation. Recently, endoscopic-assisted exposure of the lateral portion of the IAC allows complete removal of intracanalicular tumor through the retrosigmoid approach with less opening of the IAC [1, 43–45].

The retrosigmoid approach can be performed in supine, park-bench, or semi-sitting position. The semi-sitting position has the advantage of spontaneous drainage of cerebrospinal fluid (CSF) and blood, which provides a clean surgical field, thereby minimizing the retraction of the cerebellum and reducing the dissection time. The main risks of the setting position are brachial plexus injury and the development of venous air embolism with subsequent pulmonary embolism or even cerebral embolism in case of patent foramen oval. The complications of semi-sitting position can be avoided by the monitoring of somatosensory evoked potentials (SSEPs) during patient positioning to avoid brachial plexus injury, intraoperative monitoring of CO_2 and trans-esophageal echocardiography, as well as application of central venous catheter with the tip positioned close to the superior vena cava junction with the right atrium are important to detect the venous air embolism in the early stage, hence avoiding subsequent complications [45]. Even patients with a patent foramen oval can be operated safely in the semi-sitting position under standardized anesthesiological and neurosurgical protocols [46].

3.3.2. Intraoperative neurophysiological monitoring

Intraoperative neurophysiological monitoring in VS surgery is associated with increasing rates of hearing and facial nerve preservation. In addition, it helps to predict the postoperative functional outcome and hence helps the surgeon preoperatively counsel the patient regarding the postoperative hearing and facial nerve outcome.

Direct electrical stimulation and continuous free running electromyography (EMG) monitoring considered the gold standard for intraoperative facial nerve monitoring. However, the role of monitoring of facial nerve motor evoked potentials is still controversial [47].

Through direct electrical stimulation of the facial nerve, the EMG activity of the facial muscles is recorded. Early facial nerve identification during surgical removal of large VS is very helpful in preventing damage to the facial nerve during tumor dissection [48]. Several studies have provided parameters that can predict the postoperative facial functional outcome. The most widely accepted parameters are stimulation threshold and absolute EMG amplitude following stimulation at the root exit zone from the brainstem [49–53]. A study showed that proximal-to-

distal EMG amplitude ratios (comparing the response from stimulation at the brainstem to the response at the internal auditory canal) were more predictive for initial postoperative nerve function and for functional recovery than absolute EMG potentials or stimulation thresholds [48, 54].

Continuous EMG recording from facial muscles gives important information that helps in identification of the facial nerve during tumor dissection, so it is used in conjunction with direct nerve stimulation. It has been showed that continuous sinusoidal symmetric EMG signal of high-frequency and low-amplitude known as "A" trains are predictors of poor postoperative facial nerve function [55–57].

The brainstem auditory evoked potential (BAEP) is the most widely used intraoperative electrophysiological method for auditory function monitoring because it has a high sensitivity and reliability to detect cochlear nerve damage. Classically, BAEP comprises 5–7 waves. During surgery for VS, wave III and wave V are the most relevant and should be closely monitored. The surgeon is alerted when the change in latency of Wave V exceeds 0.5 ms or if any wave is significantly changed or disappeared [47].

Direct cochlear nerve action potential monitoring has been used in multiple centers, and it represents a near-field technique in which electrodes are placed close to the cochlear nerve. Therefore, larger amplitude signals are produced and acquisition takes only 2–3 s (in contrast to minutes with BAEP), thus allowing near real-time feedback to the surgeon [47].

3.3.3. Surgery results

Total removal of VS is possible by dissecting the neurovascular structures from the false capsule of the tumor [58]. Although total tumor removal should be the aim in VS surgery, near-total removal is also accepted when a thin layer of tumor is intentionally left attached to one or more nerves in an attempt to preserve the neurological function. The results of long-term rates of tumor control do not differ significantly between cases of gross total resection and cases in which a small amount of tumor is left behind [59]. Recurrent tumors should be treated by radiosurgery whenever possible, as repeat surgery is more difficult; however, in case of large recurrent tumors or radiosurgery failure, repeat surgery will be needed [59] (**Figures 3** and **4**).

It has been reported that anatomical preservation of the facial nerve is achieved in 93–99% of VS surgeries [23, 58, 60–64]. Although transient deterioration of facial nerve function usually occurs after surgery, gradual recovery usually follows during the first 3–6 months postoperatively. The main predictor of facial nerve preservation after surgery is tumor size [65–68].

The rate of hearing preservation following surgery for VS varies widely in the literature. The most significant factors predicting hearing preservation are tumor size and extension, and preoperative hearing level. Some authors have suggested that hearing preservation surgery should be undertaken only for small- or medium-sized VSs [25, 65, 69–71]. However, hearing preservation may be possible even with large VS. Hearing preservation rates of 9.1–50% have been reported for tumors >3 cm [72–78] and 22.2–56.3% for tumors >2 cm [58, 62, 79, 80]. Therefore, patients with functional preoperative hearing should be offered hearing preservation surgery with intraoperative monitoring of hearing function.

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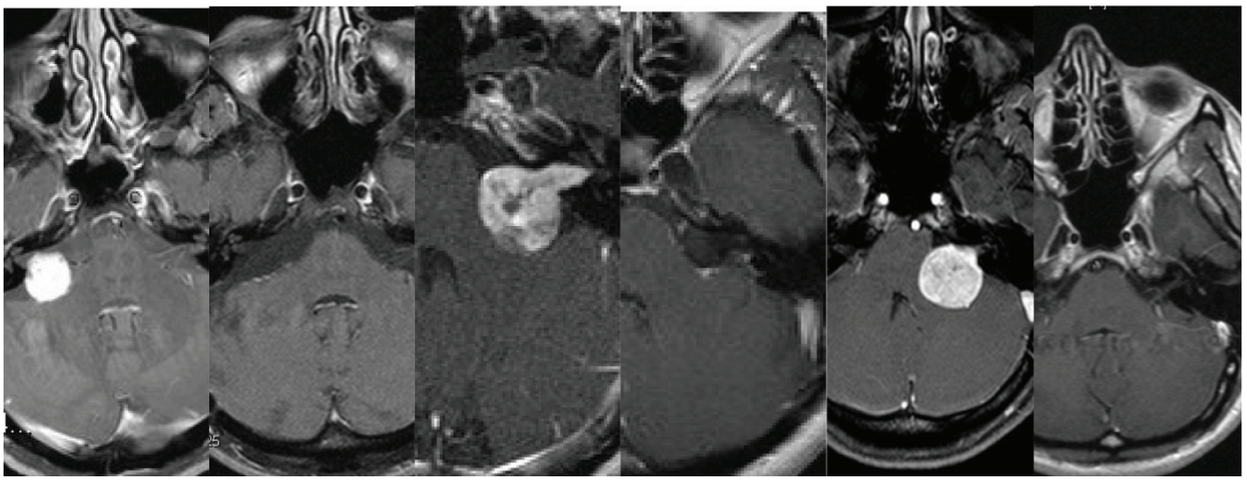

Figure 3. Axial MRI (T1-with contrast) of three operated cases (complete removal-retrosigmoid approach) with follow-up MRI after 31 months (case on the left side), after 29 months (case on the middle), and after 17 months (case on the right side) showing no tumor rest or recurrence.

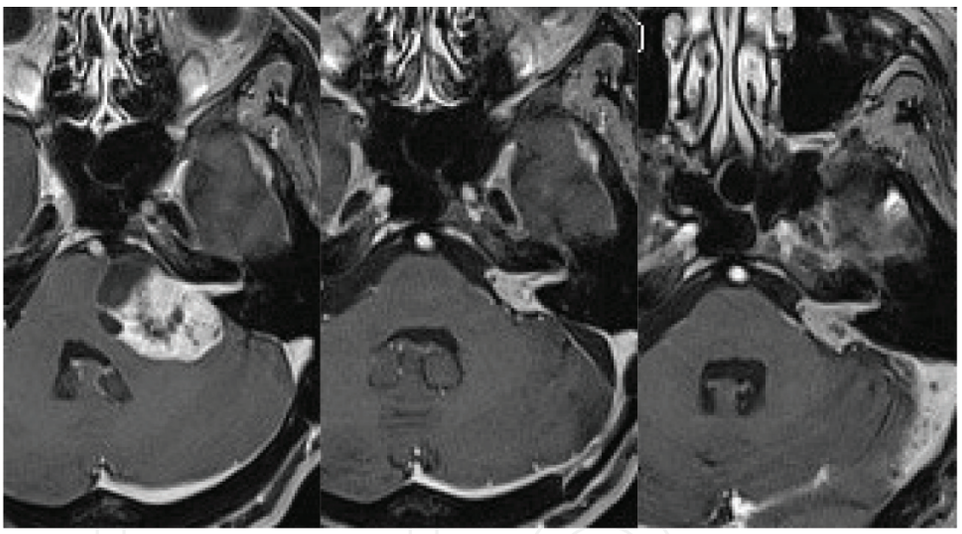

Figure 4. Axial MRI (T1-with contrast) of a case of partially cystic VS (T4a), subtotal removal-retrosigmoid approach. Follow-up MRI after 18 months (image in the middle) showed residual tumor, after 31 months (image on the right) showed progress in size of the residual tumor, so that radiosurgery was indicated.

The results of a large systematic review evaluating the use of microsurgery in more than 5000 patients with VS with a mean follow-up of 66 months, revealed tumor control rate of 98.2%, hearing preservation outcome of 36%, facial neuropathy in 13%, CSF-leak in 6%, and mortality rate of 0.6%. In a cohort of about 1000 patients with tumors smaller than 3 cm in diameter, they reported hearing preservation outcome of 49% and facial neuropathy in 10% [81].

In their meta-analysis on small VS cases (size less than 2 cm in diameter) with follow-up more than 5 years, Maniakas and Saliba included 153 operated cases. They reported tumor control

rate of 98.7% and the overall hearing preservation outcome of 50.3%, while facial neuropathy rate was ranged from 0 to 5.3% per study and trigeminal neuropathy in 0% [39].

Ahsan et al. performed a systematic review and meta-analysis on long-term hearing preservation after resection of VS, and they reported immediate postoperative hearing preservation rate of 50–70%; in addition, the hearing durability at 5 years was found to be 70% [82].

Possible complications of surgery include CSF leakage in 3–13% [72, 83], postoperative hemorrhage in 2.2% [84], meningitis in 0.8–2.5% [85, 86], lower cranial nerve deficit in 0.5–5.5%, and hydrocephalus in 1–3% [84]. The possible complications associated with microsurgery may result in death; however, mortality rates are very low; a 3-month mortality rate of 0.5% was recently reported in a hospital-based study that included 2643 VS surgeries in 265 US Hospitals [87].

3.4. Studies comparing microsurgery and radiosurgery

To the best of our knowledge, currently, there is no class 1 evidence to support one treatment modality for vestibular schwannoma (VS). There are six studies that compared microsurgery (MS) and radiosurgery (RS) for treatment of VS, two of which are prospective controlled studies with predefined inclusion criteria [88, 89]. The other four studies are retrospective cohort studies with a matched control group, all comparing microsurgery with radiosurgery [90–93]. The results of these studies are summarized in **Table 3**. The relatively small patient groups, short follow-up periods, and heterogeneity in the comparison groups are potential weaknesses of some of these comparison studies [94].

3.5. Summary of the literature review

Until additional prospective comparisons or randomized trials can be accomplished, systematic meta-analysis of the available literature offers the most powerful guidance for clinical

Authors and publication year	**Pollock 2006**	**Myrseth 2009**	**Pollock 1995**	**Myrseth 2005**	**Regis 2002**	**Kaprinos 2000**
Follow-up (mean in months)	42	24	36	69	36	MS 24 RS 48
Tumor control	Not included	Not included	Not included	94.2% (MS) 89.2% (RS)	Retreatment MS (9%) RS (3%)	100% (MS) 91%(RS)
Hearing preservation (%)						
MS	5	0	14	5	36	40
RS	63	68	75	32	50	44
Facial preservation (%)						
MS	83	82	78	80	67	64.7
RS	98	100	91	95	100	93.9

Table 3. Cohort studies comparing microsurgery (MS) and radiosurgery (RS) for solitary VS.

decisions. We have performed analysis of the available meta-analyses in the literature that reported the results of MS and RS for treatment of VS. The results of tumor control rate ranged between 98.2 and 98.7 in MS [39, 81], and between 91 and 96.2% in RS [26, 30, 38, 39]. The results of hearing were found to be higher in small tumors both after MS as well as after RS, with rates of hearing preservation 39–70% after MS [39, 81, 82] and 44–79.1% after RS [26, 30, 38, 39]. The results of facial neuropathy following Gamma Knife and CyberKnife RS ranged between 0 and 2% [26, 39]; however, LINAC was associated with 6.9% risk of facial neuropathy [39]. The rate of facial neuropathy following MS is highly dependent on tumor size and experience of the surgery team as well as the use of intraoperative neuromonitoring, and the results ranged widely between 0 and 13% in the reviewed meta-analyses [39, 81].

Author details

Ahmed Rizk[1,2*]

*Address all correspondence to: arizkrizk@gmail.com

1 Benha University Hospital, Benha, Egypt

2 Barmherzigen Brüder Hospital, Trier, Germany

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