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Management of Vestibular Schwannoma with Normal Hearing

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Keywords
Vestibular schwannoma · Normal hearing · Hearing preservation · Wait and scan · Facial nerve outcome

Abstract
Introduction: This work aimed to study the management of vestibular schwannoma (VS) patients with normal hearing (NH). ***Methods:*** A retrospective study was undertaken in a Quaternary referral center for skull base pathologies. Among 4,000 VS patients 162 met our strict audiological criteria for NH. These patients were divided into 2 management groups, wait and scan (W&S) (45/162, 25%) and operated patients (123/162, 75%), and 6 patients were included in both groups. ***Results:*** Our management strategy achieved the goals for treatment of VS. First goal, all tumors were completely removed except for 2 intentional residuals. Second goal, facial nerve (FN) function preservation (House Brackmann I, II, and III) was 95.9%. Third goal, possible hearing preservation (HP) attempts occurred in (50/122) (40.9%) with an HP rate in 44% of the patients. Additionally, there were only 2 cases of postoperative complications with no CSF leakage. The prospect of HP in NH patients did not differ with respect to tumor size. However, patients with normal preoperative ABR seemed to have better chances of HP and good FN function and vice versa. HP rate was superior for the MCFA as opposed to the RS + RLA. W&S group demonstrated hearing stability in 88.9% of the patients and FN function stability of HB I in 100% of the patients. ***Conclusions:*** Surgical resection is a reasonable and definitive management option for VS with NH. Nevertheless, choosing to manage cases with observation remains an appropriate management option for NH patients. ABR might be considered as an adjuvant tool indicating better prognosis for HP.

Introduction

Increased awareness along with technical refinements in radiologic investigations has led to early diagnosis of vestibular schwannoma (VS) with normal hearing (NH). Since continuous tumor growth may cause life-threaten-

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ing complications, hearing and cranial nerve function becomes negligible in considerable tumor sizes, and tumor removal is of paramount importance. However, once serious risks could be excluded, one could argue that hearing should be the main assessment factor when evaluating decision-making and disease progression. Moreover, facial nerve (FN) function is rarely affected during observation [Stangerup and Caye-Thomasen, 2012]. However, with the advent of hearing preservation (HP) surgeries, namely the middle cranial fossa approach (MCFA) and the retrosigmoid approach (RSA), surgical intervention has drifted toward patients with smaller tumors and better hearing [Babu et al., 2013].

There is a consensus in the literature that the most prognostic indicators for successful HP are tumor size <10 mm, good preoperative hearing and high speech discrimination score (SDS), shorter hearing loss period, and tumors from SVN [Bakkouri et al., 2009; Carlson et al., 2018; Huo et al., 2019]. In addition, there is some evidence that the auditory brainstem response (ABR) can provide prognostic information on prospects of HP [Brackmann et al., 2000; Hosoya et al., 2019; Zanoletti et al., 2020], since the ABR depends on neural synchrony and centripetal auditory-pathway integrity. The aim of the present work was to define an appropriate algorithm for the management of VS in a patient with NH can be diagnosed.

Patients and Methods

This study was carried out in the Department of Neurotology & Skull Base Surgery Gruppo Otologico, Piacenza-Rome, Italy. Four thousand versus patients' records managed by our center, from 1986 to 2017, were retrospectively reviewed. Patients affected by neurofibromatosis type 2 were excluded. Hearing function was graded according to the Modified Sanna classification (MSc) [Kanzaki et al., 2003]. Pure tone average was calculated using air conduction thresholds at 500, 1,000, 2,000, and 4,000 Hz. The SDS was also assessed. NH criteria are a pure tone hearing threshold (from 250 to 8,000 Hz) ≤25 dB HL, SDS in quiet >90%, and interaural differences ≤10 dB at each frequency. Only patients with NH were selected.

ABR was performed at diagnosis and was categorized into 6 types as follows: 1 – normal, 2 – distorted/absent waves (no delay), 3 – delayed interaural latency difference (ILD) ≥0.2 ms, 4 – delayed and distorted waves, 5 – extremely delayed ILD-V or ILD I-V ≥1 ms, and 6 – absent. The FN function, pre- and postmanagement, was graded according to the House-Brackmann (HB) grading system [House and Brackmann, 1985].

The tumor size was measured as the maximum diameter of the extrameatal portion of the tumor in any plane on magnetic resonance imaging (MRI), and graded according to the Tokyo Consensus Meeting on Systems for Reporting Results in VS [Kanzaki et al., 2003]. Tumor size data were collected from computerized tomography scans for 2 patients. We calculated tumor growth rate according to the following formula [Lovato et al., 2019]:

(Tumor size at last MRI − tumor size at first MRI)/time between first and last MRI.

We tailored the management of each case by taking into consideration the age, symptoms, tumor size, fundus status, contralateral hearing, FN function, and the patient's personal preference. The risks and benefits of all 3 management options (namely: wait and scan [W&S], surgery, and radiotherapy) were discussed with each patient. All subjects gave written informed consent on the use of their data and prior to any surgical intervention.

The selection of the surgical approach is guided by a series of goals: first, adequate tumor removal, followed by FN preservation, and lastly, HP. The designated criteria for management approaches are described in Table 1.

Statistical Analysis of the Data

Microsoft Office Excel 2016 was used for data management. The data were analyzed using the IBM SPSS software package version 20.0. Mean and standard deviation were calculated for parametric variables. χ^2 and Fisher's exact tests were used to compare nonparametric variables. Independent samples *t* test (normal distribution) or Mann-Whitney U test (nonnormal distribution) was used to compare subgroups. Pearson's test was used for correlation with r-value. A p value ≤0.05 was considered for statistical significance.

Results

Among the 4,000 VS patients treated in our center, records with sufficient data were available for 3,768 patients. Of these, 162 met the criteria for NH (4.2%). Since none of our patients chose radiotherapy, our patients were divided into 2 groups, namely W&S and surgery. The surgical approaches were all carried out by the senior surgeon (M.S.). Descriptive data of patients in both groups are depicted in Table 1.

Surgery

Our three goals of management achievements are presented in Table 2. At the last F/U, postoperative FN function HB grade I and II occurred in 70.3% of cases. In total, 95.9% of the patients presented an acceptable FN function (HB grade I-II-III), as shown in Table 2. Five cases had a preoperative FN function HB grade II-III, which remained unvaried postoperatively. The FN was transected in one case and was immediately reconstructed by a sural nerve graft. The patient obtained an FN grade IV. A delayed facial palsy occurred in 2 patients; these latter cases were operated via MCFA, and they recovered to grade I and II at the last F/U. There was no relation between the surgical approach and the final FN grade ($p = 0.62$). Good

Table 1. Descriptive data of the surgery and W&S groups

Patients	Surgery	W&S
Designated for	Only MSc classes A and B (PTA <30 dB HL and SDS >70%) were considered for HP surgery *RS/RLA: for tumors that did not reach the fundus of the IAC with an extrameatal component of 1.5 cm *MCFA: < 60 years of age, with tumors reaching the fundus and an extrameatal extension <0.5 cm *TLA: tumor >2 cm extrameatally	*Asymptomatic patients *Lower tumor grades (0, 1, and 2) *Age >40 years *High surgical risk *Tumor in the only hearing ear
Patients, *n*	123–1 = 122 One patient did not proceed with his surgery	45–18 = 27 Eighteen (40%) patients were lost at F/U Results from the remaining 27 were analyzed
	Six patients (6/162) (3.7%) failed W&S and were surgically treated due to tumor growth and they were included in both groups	
Mean age	38.67 years (10.0–67.0 years)	44.7 (16.0–73.0 years)
Female predominance, %	68.3	66.6
Right side, %	51.2	51.8
Mean duration of postoperative F/U	3.90 years (0.08–19.0 years)	3.38 years (0.33–11 years) (F/U duration was <1 year for 1 patient who was diagnosed recently)
Fundus occupied	69/115 (60%) (fundus data available for 115 patients)	18/27 (66.6%)
FN function	Only 5 patients had a preoperative FN function HB grade II-III, and the rest of the patients had HB grade I	Normal FN function in all patients
ABR at diagnosis	Patients undergoing an HP approach: data available for 47 patients Abnormal 72.3% Normal 27.6%	Normal in 13/27 (48.1%) Abnormal 14/27 (51.8%) ABR of the contralateral side was normal in all patients
Interventions	Surgical approaches used *TLA in 59.3% *MCFA in 20.3% *RS/RLA in 20.3%	Periodic MRI scans simultaneously with clinical and audiological evaluations 1 – yearly for the first 5 years after diagnosis 2 – every other year for the following 5 years 3 – followed by a scan every 5 years

MSc, Modified Sanna classification; PTA, pure tone average.

FN function (HB grade I and II, respectively) at the last F/U was achieved in 76%, 88%, and 76.9% of the case for MCFA, RS + RLA (retrolabyrinthine approach), and translabyrinthine approach (TLA), respectively. There was a statistically significant relationship between smaller tumors and better final FN grade ($p < 0.001$). There was no relationship between fundus status and final FN function ($p = 0.3$).

An HP approach was chosen in 50/122 patients (40.9%) and results are demonstrated in Table 2. There was a statistically significant association between postoperative serviceable hearing and MCFA approach ($p = 0.015$), while postoperative anacusis was more frequent after RS + RLA ($p = 0.007$).

Tumor grades are represented in Table 3. MCFA was performed more frequently in grade 0 tumors, RS + RLA more for grade 1, and TLA was performed more for ≥grade 2. No relationship between tumor grade and postoperative hearing was inferred ($p = 0.8$). We did not compare surgical approaches to fundus status as MCFA was never used for fundus free patients.

Table 2. Management goals' achievements

Goals		
Total tumor removal	*Total gross removal*	*Residual/recurrence*
	98.4% (120/122) of the patients	2 Residual tumors were left (1 after a TLA & 1 after an MCFA) 1 Recurrence occurred after 7 years (after MCFA)
FN function, *n* (%)	*FN at discharge* (n = *121)*	*Final FN* (n = *121) (at the last F/U)*
1 (normal)	52 (43.0)	60 (49.6)
2 (near normal)	12 (9.9)	25 (20.7)
3 (moderate)	14 (11.6)	31 (25.6)
4	5 (4.1)	3 (2.5)
5	4 (3.3)	1 (0.8)
6	34 (28.1)	1(0.8)
HP 50/122 patients (40.9%)	Serviceable hearing (MSc classes A-B) at the last F/U in 22 patients (44%) Mean postoperative PTA was 27.1 dB HL (range 11.0–40.0) SDS range was 90.0–100.0%	Immediate postoperative hearing level varied in 13 patients (26%) 7 patients (14%, 5 MCFA, 2 RS-RLA) worsened during F/U 5 patients (10%) (4 MCFA, 1 RS-RL) improved from nonserviceable to serviceable

PTA, pure tone average.

Table 3. Distribution of the studied cases according to Tokyo Consensus Meeting on Systems for Reporting Results in VS in Surgery group (*n* = 123) and W&S group (*n* = 27)

Tumor grade classification	Surgery (*n* = 123)		W&S (*n* = 27)	
	n	%	*n*	%
0 (intrameatal)	34	27.6	21	77.7
I (small: 1–10 mm extrameatal)	42	34.1	4	14.8
II (medium: 11–20 mm)	26	21.1	2	7.4
III (moderately large: 21–30 mm)	12	9.8	0	0
IV (large: 31–40 mm)	6	4.9	0	0
V (giant: >40 mm)	3	2.4	0	0

The ABR, when available (n = 47), was abnormal in 72.3% of the patients undergoing an HP approach. There was a statistically significant relationship between preoperative ABR and postoperative hearing, as depicted in Table 4; all patients resulting in a total hearing loss had preoperative abnormal ABR, mostly type 5. All class A patients, except one, had normal ABR and class B patients had mostly type 3 ABR (p = 0.001).

No postoperative symptoms were reported by 51.2% of the patients. The major complaints are shown in Table 5. Most of these symptoms resolved during F/U. TLA was significantly associated with less postoperative symptoms than the other approaches (p = 0.017). No significant relationship was found between a specific postoperative symptom and the surgical approach except for postoperative headache which was significantly associated to RS + RLA (p = 0.033). There was one case of immediate postoperative subcutaneous hematoma operated by TLA and another case of meningitis operated by MCFA. There were no cerebrospinal fluid leaks in this series.

Wait and Scan

All W&S patients presented a normal FN function which was maintained during all F/U period. The last available hearing measurements during F/U had a mean of 24.31 dB HL (range 20.0–72.50 dB HL), as shown in Table 6. The rate of hearing loss was 2.81 dB HL per year. Hearing deteriorated in 11.1% of the cases. Hearing improved in 1 patient (class B to A). Growth occurred in 10/27 (37%) patients, 7 of which were intrameatal and 3 were extrameatal. Two patients, with intrameatal tumors, had mixed growth pattern (no growth/growth/no growth), so, we proceeded with further W&S. The mean growth was 6.25 mm with a growth rate of 2.76 mm per year. The initial tumor size at diagnosis was not found to affect neither the rate of hearing loss (p = 0.6) nor the tumor growth (p = 0.8). Similarly, there was no association between hearing loss and tumor growth (p = 0.088). Most patients with abnormal ABRs (58%) presented tumor growth, while only 18.2% of patients with normal ABR had tumor growth, although it did not reach statistical

Table 4. Relation between ABR and postoperative hearing in Surgery group [Surgical approach: MCFA, RS + RL]

Postoperative hearing	ABR				χ^2 test	^{MC}p value
	normal (n = 13)		abnormal (n = 34)			
	n	%	n	%		
A	5	38.5	1	2.9	17.935*	0.001*
B	5	38.5	10	29.4		
C	1	7.7	1	2.9		
D	0	0.0	2	5.9		
E	1	7.7	3	8.8		
F	1	7.7	1	2.9		
Total HL	0	0.0	16	47.1		

MC, Monte Carlo. p value for association between different categories. * Statistically significant at $p \leq 0.05$.

Table 5. Distribution of the studied cases according to F/U postoperative symptoms in Surgery group (n = 122)

F/U symptoms	n	%
No new symptoms	63	51.2
Tinnitus	30	24.4
Instability	22	17.9
FN symptoms (e.g., synkinesis, crocodile tears, hemifacial spasm)	20	16.3
Trigeminal nerve symptoms (e.g., hemifacial dysesthesia and hypoesthesia)	4	3.3
Headache	6	4.9
Meningitis	1	0.8

Table 6. Distribution of the studied cases according to MSc hearing classification in W&S group (n = 27)

Hearing classification	PTA, dB	SDS, %	n	%
A	0–20	100–80	18	66.7
B	21–30	79–70	6	22.2
C	31–40	69–60	2	7.4
D	41–60	59–50	0	0
E	61–80	49–40	1	3.7
F	≥80	39–0	0	0

PTA, pure tone average.

significance (p = 0.08). The ABR could not predict the progression of hearing over F/U periods (p = 0.88). To be noted that results on tumor growth might reflect a bias due to the small number of patients (10 patients), which mandates replication of these relations on a larger group of patients to draw a definitive conclusion.

During the W&S period, 25.9% of the patients reported new symptoms: instability, hearing loss, vertigo, and tinnitus. These symptoms were related neither to tumor growth nor to the duration of the W&S.

Discussion

Modern imaging often detects VSs, while they are still small and cause minimal symptoms. The management is generally tailored to each patient, according to several patient and tumor factors along with an institutional philosophy [Liu et al., 2015; Saliba et al., 2019]. Authors debate on whether to perform HP surgery as early as possible in order to preserve hearing before it deteriorates, or to postpone surgery, given the poor hearing results of these surgeries [Walsh et al., 2000]. The identification of reliable preoperative predictive factors would allow better counseling of patients on their prognosis in case of HP surgery or the need to consider alternative options. However, no consistent factors have been found to date that provide a high level of prediction [Goddard et al., 2010].

Approximately 75% of intrameatal VSs and 60% of extrameatal VSs do not grow in the 10 years following diagnosis, and more than 80% of VSs are not expected to fail W&S [Reznitsky et al., 2020]. In the present study, we report the management of 162 VS patients with NH, who were managed by W&S and/or surgery, aiming to delineate which patients are realistic candidates for HP. In our institution, primary goals in VS management are adequate tumor removal followed by FN preservation and lastly HP. In case of W&S, the first goal can subside if the

tumor is dimensionally under control, that is, if there is no risk of compression and shows no evident growth at periodic imaging.

Tumor Removal/Tumor Control

Indisputably between the two managements, only surgery can secure tumor removal while possibly preserving hearing [Saliba et al., 2019]. A patient accepting to undergo W&S bears the psychological burden of having a "brain tumor" [Walsh et al., 2000]. Moreover, the patient must abide by a prolonged F/U and the cost of the annual imaging (which will be initially identical to the postoperative imaging of patients undergoing surgery). Although the probability of tumor growth plummets steadily and significantly in the first 5 years [Sethi et al., 2020], a minority of patients might show a delayed growth which makes long F/U essential [Macielak et al., 2019]. Unfortunately, up to 40% (18/45) of the patients who chose the W&S management at our center were not compliant.

The majority of VSs grow at a rate of ≤2 mm per year [Saliba et al., 2019]. However, there are no parameters that predict which tumor will grow and to what extent [Smouha et al., 2005]. In a systematic review [Nikolopoulos et al., 2010], growing tumors ranged from 6 to 73%, and the mean growth rate ranged from 0.3 to 4.8 mm per year. Many studies reported the growth rate of extrameatal tumors to be higher than that of intrameatal ones [Smouha et al., 2005; Bakkouri et al., 2009]. In the present study, tumor growth occurred in 37% (10/27) of patients, 33% of the intrameatal tumors (7/21), and 50% (3/6) of the extrameatal ones. The growth rate was 2.76 mm per year. Interestingly, initial tumor growth was not a criterion to refer the patient directly to surgery. Two intrameatal cases showed no growth after initial growth. As shown by some authors, a mixed growth pattern could be indicative to proceed with further W&S [Ferri et al., 2012; Patnaik et al., 2015].

Some authors proceeded with surgery in 6–24% of their W&S patients [Shin et al., 1998; Yates et al., 2003; Bakkouri et al., 2009]. Reznitsky et al. changed to active treatment due to tumor growth in 19% of their observation patients, 16% of these patients underwent surgery, and 3% received radiotherapy [Reznitsky et al., 2020]. Reddy et al. reported surgery after failed W&S in 44.4% of their cases [Reddy et al., 2014]. In our study, 6/27 (22.2%) of the cases failed W&S and required intervention due to tumor growth, similar to another study [Reznitsky et al., 2020]. However, according to Johnson et al. [2019], only 3.1% of patients undergoing primary radiotherapy will have to undergo additional management for tumor growth.

On the other hand, surgery offers complete tumor removal and not an arrest of further tumor growth. Among the tumors surgically treated, all but two tumors were totally removed. A residual tumor was left in these two cases due to adherence to the FN. The residues did not grow during F/U. A single recurrence (0.8%) occurred after an MCFA, 7 years after surgery. In general, tumor recurrence after surgical removal is very rare, accounting for 0.4–2% of cases [Yamakami et al., 2004].

In this series, a TLA was performed in 59.3% of the operated cases. According to large series, the TLA offers a significantly higher probability of total removal, minimal cerebellar/brainstem manipulation, better FN preservation, and minimal cerebrospinal fluid leak, especially in tumors reaching the fundus of the IAC and in patients above 60 years [Sanna et al., 2004; Ben Ammar et al., 2012]. Accordingly, we adopted TLA for patients who had preoperative FN (5 patients) symptoms for better salvage of the nerve, occupied fundus (60% of TLA patients) and tumor size >2 cm (30% of TLA patients). According to the congress of neurosurgery recent guidelines of level 3 evidence, "The degree of lateral IAC involvement by tumor adversely affects facial nerve and hearing outcomes and should be emphasized when interpreting imaging for preoperative planning" [Dunn et al., 2018]. Therefore, in some patients with tumors <2 cm but completely filling the IAC and considering the null risk of preserving hearing, we adopted the TLA approach to completely remove the tumor while saving the FN. In addition, a portion of the patients were diagnosed and treated before the emergence of HP surgeries and W&S. This explains the higher number of TLA cases in our study despite the criteria for approach selection set in our institute. Our philosophy is to achieve complete resection in younger patients (most of the study patients) because they have a longer life expectancy and likely higher risk of growth resumption; therefore, partial resection was not adopted in this specific subset of patients. However, there is undoubtedly merit in the concept of near total and subtotal resection for preservation of important neurovasculature, especially the FN.

Hearing Function

HP theoretically relies on the integrity and normal function of the internal auditory artery, the inner ear structure, and the cochlear nerve [Han et al., 2010]. Although simultaneous cochlear implantation and tumor removal are possible through the TLA in selected cases

[Lassaletta et al., 2016], this approach does not preserve any cochlear reserve and is therefore challenging to recommend in patients with NH. The analysis of literature regarding HP is challenging due to inconsistent reporting of hearing, variable inclusion criteria, and a nonuniversal definition. HP rates after VS removal vary from 20% to 71% [Goddard et al., 2010].

In the present series, HP was attempted in 50/122 (40.9%) of patients undergoing surgery. Preservation of serviceable hearing at the last F/U (Classes A & B) was reached in 22/50 (44%) patients. There was a statistically significant association between postoperative serviceable hearing and MCFA ($p = 0.015$), while total hearing loss was more associated to RS + RLA ($p = 0.036$). Thus, in accordance with other studies [Staecker et al., 2000; Sughrue et al., 2010], HP is more frequently achieved with MCFA compared to RS + RLA. However, it should be acknowledged that RS + RLA is favored in case of larger tumors [Woodson et al., 2010]. According to Yamakami et al., there was no difference between the two approaches [Yamakami et al., 2014]. A recent meta-analysis concluded that MCFA yielded better hearing results than retrosigmoid approach; however, this difference is subjected to the influence of selection bias caused by tumor size and location [Hunt et al., 2020].

Our HP results are in accordance with the extant literature. Nonetheless, we applied the Modified Sanna classification and not the AAO-HNS system, which reflects more accurate and realistic estimates of hearing without overestimating the usefulness of the preserved hearing. In our hands, when anatomically possible, the MCFA was the best approach for achieving HP. The RS-RLA finds its place in larger tumors with a free fundus. Delayed hearing loss occurs in 11–30% of patients after VS surgery [Friedman et al., 2003; Woodson et al., 2010].

In this study, 2/50 (4%) patients developed a delayed hearing loss (class B to C), and they had both undergone an RS + RLA. Similarly, to other authors, none of the patients undergoing an MCFA developed a delayed hearing loss [Friedman et al., 2003; Woodson et al., 2010]. Unlike the results of one of the recent largest series of VS [Ichimasu et al., 2020] in which 13% lost their useful hearing during the long follow-up period, all of our patients had stable preserved useful hearing during the long follow-up period, except for 2 patients. Another recent systematic review [Reznitsky and Cayé-Thomasen, 2019] showed that after 5 years of observation, around half of patients will have preserved good or serviceable hearing. On the other hand, a recent study [Coughlin et al., 2019] demonstrated that radiation therapy long-term HP rates are poor; an approximately 80% HP rate at 2 years posttreatment falls to approximately 23% at 10 years.

Good preoperative SDS and/or pure tone average, tumor size (<1 cm), and favorable ABR recordings are prognostic features associated with HP [Hecht et al., 1997; Hosoya et al., 2019; Huo et al., 2019]. Moreover, hearing has been demonstrated to being preserved better in patients with 100% SDS at diagnosis than in patients with even a small loss of SDS [Kirchmann et al., 2017].

As aforementioned, the ABR is considered by several studies as an effective prognostic tool in predicting hearing outcome [Matthies and Samii, 1997; Brackmann et al., 2000; Hosoya et al., 2019]. For some authors, an abnormal ABR does not represent a contraindication to pursue HP [Rohit et al., 2006; Yang et al., 2008]. This variability might be due to the different criteria of ABR evaluation adopted by different studies. In the present study, a significant relationship was obtained between preoperative ABR and postoperative hearing. When ABR abnormality increased postoperative hearing worsened ($p = 0.001$). In agreement with other authors [Brackmann et al., 2000; Zanoletti et al., 2020], type 5 ABR was associated with a poorer postoperative hearing. All the cases with postoperative anacusis had a preoperative abnormal ABR, mostly type 5. Likewise, all except one case (5/6; 83.3%) with postoperative class A hearing had a normal preoperative ABR. We consider ABR a predictive of the hearing outcome.

On the other hand, tumor size was not an independent prognostic factor for postoperative HP in this study ($p = 0.8$), in agreement with other authors [Brackmann et al., 2000; Hosoya et al., 2019; Huo et al., 2019]. This result could be attributed to the fact that the majority of our tumors (61.7%) were small (grade 0 and 1), and that all of our patients had NH. Hearing was preserved in Grade 0, 1, and 2 in 7/26 (26.9%), 8/18 (44%), and 2/6 (33%) cases, respectively.

Some authors [Walsh et al., 2000; Fayad et al., 2014; Reddy et al., 2014; Prasad et al., 2018] showed that a faster tumor growth (>2.5 mm/year) was positively correlated with hearing loss. Conversely, hearing impairment could occur irrespective of tumor growth [Walsh et al., 2000; Rohit et al., 2006; Reddy et al., 2014; Saliba et al., 2019]. In our study, there was no association between the rate of hearing loss and that of tumor growth. Moreover, among patients undergoing W&S, hearing deteriorated in 11.1% of the cases regardless of tumor growth after a mean F/U of 3 years. The patients presented an overall rate of hearing loss of 2.81 dB HL per year. Fayad et al.

[Fayad et al., 2014] reported hearing deterioration in 14.3% of the cases after an average F/U of 4.8 years. According to [Kirchmann et al., 2017], serviceable hearing was preserved in 34% according to AAO-HNS and in 58% according to the word recognition score after a mean F/U of 9.5 years.

It is undeniable that W&S is the best management for preserving hearing (88.9% in W&S vs. 44% in HP surgery). However, if only patients with a preoperative normal ABR are considered, the probability of postoperative serviceable hearing after HP surgery rises to more than 80%. On the other hand, all patients with an abnormal ABR, especially if type 5, have an almost null probability of HP and should therefore undergo surgery through an approach that conveys the highest probability of total tumor removal with a minimal risk of complications.

FN Function

The current preservation rate of FN function reaches 80–90% for tumors of 30 mm or smaller and 70% for tumors larger than 30 mm [Han et al., 2010; Dandinarasaiah et al., 2019]. The most consistent predictor of FN outcome was suggested to be the tumor size [Kaul and Cosetti, 2018]. In the present study, overall preservation was of 70.3% of the cases (HB I and II), and when HB grade III is considered, it was 95.9%. Normal postoperative FN function was more associated with grade 0 and 1 tumors ($p < 0.001$), which implies that smaller tumors have better FN prognosis.

Pardo-Maza et al. reported that after immediate complete FN paralysis, no patient achieved an HB grade I and only 10% achieved grade II [Pardo-Maza et al., 2016]. All our patients with grade VI facial palsy at discharge (n = 34) improved except one. Among these patients only 1 patient recovered to an HB grade I and 3 patients to a grade II at the last F/U. Arriaga reported an improvement of FN function over time [Arriaga et al., 1993]. This suggests that anatomical preservation of the FN can be accompanied by functional improvement, even in cases of adhesions and manipulations, despite an immediate postoperative grade VI. A suggested explanation is neurapraxia and axonotmesis that may take months to recover [Kaul and Cosetti, 2018]. On the other hand, FN anatomical integrity does not necessarily correspond to good FN function. Samii et al. (2006) reported an anatomical and functional preservation of the FN in 98.5% and 81% cases, respectively.

In this study, FN preservation did not differ statistically between approaches, in accordance with other studies [Isaacson et al., 2005; Jacob et al., 2007]. FN functional preservation (HB I and II) resulted in 76%, 88%, and 76.9% of MCFA, RS + RLA, and TLA cases, respectively. FN preservation ranges from 65% to 100% in W&S series [Malhotra et al., 2009; Prasad et al., 2018]. In our study, it was 100%.

Although W&S can increase the risk of tumor progression and mass effect, it seems to be a safe approach to preserve FN function. In a well-selected population, as in this study, W&S is the most successful management in order to preserve FN function, similar to HP. However, in large or growing tumors, microsurgery would be required.

Agreeing with our results of superiority of W&S for this subset of patients, a very recent study [Ismail et al., 2022] comparing hearing outcomes of W&S and SRS concluded that patients with small- and medium-sized tumors will have a better hearing outcome if managed via an initial conservative approach with radiotherapy reserved for those demonstrating disease progression.

Limitations

As an inherent effect in retrospective analyses, our study is limited by the accuracy and completeness of few medical records of patients.

Conclusion

Surgical resection is a definitive management option for VS with NH. Preoperative ABR could be considered as an adjuvant tool in decision making and surgical approach selection. Patients with a normal preoperative ABR seemed to have better chances of HP and good FN function after surgery; therefore, HP surgery is reserved for patients with realistic possibilities of postoperative serviceable hearing. HP rate was superior for the MCFA as opposed to the RS + RLA and should therefore be preferred when the tumor is completely accessible by this approach and in younger patients. Nevertheless, choosing to manage cases with observation remains an appropriate if not superior alternative for NH patients due to a demonstrated stable hearing and FN function and a slow rate of growth. However, a careful patient selection in W&S patients along with the NH of the patients studied leads to a biased population. Hence, these results must not be generalized to all cases of VS.

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Statement of Ethics

This study protocol was reviewed and approved by the Research Ethics Committee of the Faculty of Medicine, Alexandria, Egypt, with approval No. 020984, IRB No. 00012098, and FWA No. 00018699 and also was undertaken with approval from the institutional review board for ethical research of the Casa di Cura "Piacenza," Piacenza, Italy.

All subjects gave written informed consent on the use of their data and prior to any surgical intervention.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contibutions

All named authors fulfill the ICMJE criteria for authorship. All surgeries were performed by the senior author Mario Sanna. Data collection was done by Nervana Salem and Vittoria Di Rubbo, literature review and writing were done by Nervana Salem and Ahmed Galal, revisions by Gianluca Piras and Vittoria Sykopetrites, and a critical review by Mario Sanna, Ossama A. Sobhy, and Mohamed Talaat.

Data Availability Statement

All data generated or analyzed during this study are included in this article. Further inquiries can be directed to the corresponding author.

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