Surgical Results and Technical Refinements in Translabyrinthine Excision of Vestibular Schwannomas: The Gruppo Otologico Experience

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BACKGROUND: Vestibular schwannomas (VSs) are the most common cerebellopontine angle tumors, accounting for 75% of all lesions in this location.

OBJECTIVE: To evaluate the results after removal of VS through the enlarged translabyrinthine approach, which is a widening of the classic translabyrinthine approach that gives larger access and provides more room to facilitate tumor removal and to minimize surgery-related morbidities.

METHODS: This was a retrospective study of 1865 patients who underwent VS excision through the enlarged translabyrinthine approach between 1987 and 2009. Mean age was 50.39 years. Mean tumor size was 1.8 cm. Median follow-up was 5.7 years.

RESULTS: Total removal was achieved in 92.33% of cases; 143 patients had incomplete resection with evidence of regrowth in 8. In the 1742 previously untreated patients, anatomic preservation of facial nerve was achieved in 1661 cases (95.35%), and House-Brackmann grade I or II was reached in 1047 patients (59.87%). Facial nerve outcome was significantly better in tumors ≤ 20 mm. Surgical complications included cerebrospinal fluid leakage in 0.85%, meningitis in 0.10%, intracranial bleeding in 0.80%, non–VII/VIII cranial nerve palsy in 0.96%, cerebellar ataxia in 0.69%, and death in 0.10%. The technical modifications that evolved with increasing experience are described.

CONCLUSION: The enlarged translabyrinthine approach is a safe and effective approach for the removal of VS. In our experience, the complication rate is very low and tumor size is still the main factor influencing postoperative facial nerve function with a cutoff point at around 20 mm.

KEY WORDS: Acoustic neuroma, Cerebrospinal fluid leakage, Enlarged translabyrinthine approach, Facial nerve function, Surgical complications, Vestibular schwannoma

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Vestibular schwannomas (VSs), formerly referred to as acoustic neuromas, are the most common cerebellopontine angle (CPA) tumors, accounting for 75% of all lesions in this location.[1] Advances in microsurgical techniques and neuroanesthesia, as well as the use of intraoperative neurophysiological monitoring, have led to remarkable improvements in patient outcome, reducing both mortality and morbidity. Nevertheless, one should keep in mind that surgery for VS has had a long and peculiar history, full of obstacles and tragic events with a mortality rate as high as 80% in the early 20th century.[2] The translabyrinthine approach (TLA) described by Rudolf Panse in 1904 was first performed for an acoustic neuroma excision in 1911 by Franciscus Hubertus Quix from Utrecht University Netherlands. Although this first attempt was considered successful, Quix's patient died 6 months later, and postmortem examination revealed a sizable residual tumor filling the posterior fossa.[3] Having been strongly criticized by 2 leading pioneers of world neurosurgery, namely Harvey Cushing and Walter Dandy, the TLA faded into obscurity for the next 50 years. It was not until the introduction of the surgical microscope that

ABBREVIATIONS: CPA, cerebellopontine angle; **ETLA,** enlarged translabyrinthine approach; **FN,** facial nerve; **HB,** House-Brackmann; **IAC,** internal auditory canal; **TLA,** translabyrinthine approach; **VS,** vestibular schwannoma

William House popularized the TLA again, marking the transition to the era of modern neuro-otology.[4] Since then, reduction of surgically related morbidity was the main focus of the continuous refinements to the original approach described by House. Another important key factor affecting outcome in VS surgery is surgeon experience. For that reason, reporting results of a large series of VS treated by a single surgeon gives a unique opportunity to analyze factors affecting outcomes other than surgeon expertise. Moreover, learned lessons and technical refinements that evolved with increasing experience are presented.

PATIENTS AND METHODS

From 1983 until today, the senior author (M.S.) has operated on 2472 patients with VS. The medical and neuroimaging records of all VS surgical procedures performed at the Gruppo Otologico Piacenza-Rome from April 1987 to December 31, 2009, were reviewed for the present study. Only patients operated on through the enlarged TLA (ETLA) with at least 1 year of follow-up and with no evidence of neurofibromatosis were included in the analysis. After surgical resection, patients were followed up at the outpatient clinic at the third, sixth and twelfth postoperative months and annually thereafter. All patients included in the study had a baseline magnetic resonance imaging (MRI) or computed tomography scan at the third postoperative month, and repeat imaging was subsequently done at 1, 2, 3, 5, and 7 years postoperatively or if clinically indicated.

Approach Selection

Once the patient is advised of all treatment modalities and the decision to perform surgery is made with the medical team, several factors influence the choice of the surgical approach: tumor size and extension within the internal auditory canal (IAC), preoperative hearing on both sides, the patient's expectations, and individual decision. In our daily practice, the ETLA is adopted whenever hearing preservation is not being attempted, ie, when preoperative hearing is worse than class B according to the modified classification of Sanna et al[5] (pure tone audiogram $>$ 30 dB and speech discrimination score $<$ 70%). Moreover, in our experience, patients suffering from tumors exceeding 1.5 cm in their extrameatal diameter and those in whom tumor extends laterally into the fundus of IAC have reduced chances of hearing preservation. In those patients, we prefer to remove the tumor through the ETLA regardless of their preoperative hearing.[5]

Surgical Technique

A detailed description of the ETLA has already been published.[5] Here, we describe the approach with an emphasis on major refinements made by the senior author to improve exposure, to facilitate tumor removal, and to preserve facial nerve (FN) function. For FN identification, we use a personal technique with the superior ampullary nerve as a landmark.[6] After an extended mastoidectomy that widely uncovers the middle fossa dura, sinodural angle, and posterior fossa dura is performed, the labyrinthectomy is begun. During this step, care should be taken to preserve the most anterior part of the ampullary ends of the lateral and superior semicircular canals as landmarks. At the end of labyrinthectomy, bone left over the posterior fossa dura is removed, allowing identification of the IAC, the floor of which is uncovered by removing the bone between the latter and jugular bulb inferiorly. After the posteroinferior wall of the IAC is drilled out, exposing the inferior vestibular nerve, further drilling superiorly identifies the transverse crest, which separates the inferior from the superior vestibular nerve. The latter is continued laterally at the level of the fundus by the superior ampullary nerve, which is separated from the FN by the vertical crest or the Bill bar (Figure 1A). The superior and inferior vestibular nerves are detached with a 90° hook with the tip facing inferiorly when detaching the former. During this step, FN protected by the Bill bar can be clearly visualized and safely dissected from the tumor (Figure 1B).

Another essential point in VS surgery is bloodless technique. Within the CPA, the tumor mass is usually surrounded by an arachnoid layer that separates it from the surrounding neurovascular structures. Preservation of this natural cleavage plane is of paramount importance. If this plane is mistaken because the surgical field is replete with blood and blood clots, these noble neurovascular structures become barely distinguishable with higher risk of injury. To reach this goal, reducing the tumor size by intracapsular tumor debulking with bipolar coagulation (Vesalius molecular resonance generator) is performed. This maneuver permits

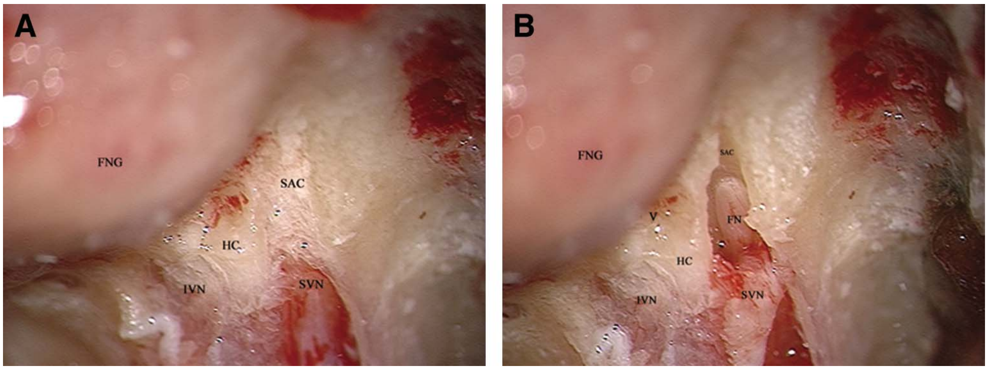

FIGURE 1. *Intraoperative microscopic view showing the superior vestibular nerve that is continued laterally by the superior ampullary nerve (A). Operative view after reflection of the superior vestibular nerve medially (B). FNG, facial nerve genu; HC, horizontal crest; IVN, inferior vestibular nerve; SAC, superior ampullary nerve canal; SVN, superior vestibular nerve; V, vestibule.*

identification and safe coagulation of tumor vessels overlying the capsule inferiorly, superiorly, and posteriorly. In the majority of cases, neurovascular structures lie anteriorly to the tumor and are hidden from view, especially in large VS with anterior extension. Blind separation of tumor from these structures should never be attempted. To overcome this problem, transapical extension (type I) of the ETLA was designed.[7] It consists of removing the bone around and anterior to the IAC between 300° and 320°, which provides direct visualization and allows surgical control of areas that were thus far considered blind zones (Figures 2 and 3). The anterior boundaries of the tumor and neurovascular structures lying anteriorly are now clearly visible, making dissection of the tumor capsule much safer.

In large VS with very medial and posterior extension, we are often limited in surgical maneuvers by the posterior wall of the external auditory canal that forms a visual barrier when we try to access and control the most posterior part of the tumor lying medially to the cerebellum and posteriorly to the level of sigmoid sinus. During dissection of the tumor from the cerebellum and to facilitate handling, the posterior wall of the external auditory canal is drilled out with blind sac closure of the external auditory meatus.[5] A high jugular bulb can be encountered in almost a quarter of the cases, making the surgical corridor very narrow. So that the surgeon can feel comfortable when handling the tumor, the jugular bulb may be displaced downward, giving more room inferiorly and enabling safe control of the inferior margins of the tumor.[8] For that, the dome of the jugular bulb is uncovered with the use of a diamond burr. Next, the bulb is dissected carefully from its wall with a septal elevator and then pressed downward with a large piece of Surgicel applied over its dome. Surgicel helps to control any bleeding that may occur during this step. A piece of bone wax is then placed over the Surgicel to keep the bulb in place and to prevent entanglement of Surgicel with the burr during further drilling.[5] With this technique, no injuries to the jugular bulb occurred, even in older patients. Closure is a fundamental step and should not be disregarded. A perfect seal could prevent postoperative cerebrospinal fluid (CSF) leakage and subsequent meningitis. All air cells should be inspected, especially at the level of facial and subfacial recesses, and patent ones must be sealed with bone wax. Furthermore, incus is removed through the additus, taking care not to dislocate the stapes to avoid leakage through the oval window. The middle ear cleft is then packed with previously collected dry periosteum, never with fat. Fat tends to dissolve on contact with air in the middle ear. This will prevent later occurrence of rhinoliquorrhea. Finally, long, thin autologous fat strips are carefully introduced deep in the CPA, and the musculofascial layer is sutured in a watertight manner, adding to the seal against leakage[9] (Figure 4).

Tumor Size

To assess tumor size, we used the classification approved in Acoustic Neuroma Consensus on Systems for Reporting Results.[10] The tumors were divided into 6 groups according to the largest diameter of their extrameatal component measured in the axial MRI or computed tomography scan sections: grade 0, purely intracanalicular lesion; grade I, 1 to 10 mm; grade II, 11 to 20 mm; grade III, 21 to 30 mm; grade IV, 31 to 40 mm; and grade V, > 40 mm. For further analysis, 2 subgroups were defined: the small VS group, including tumors smaller than or equal to grade II, and the large VS group, comprising tumors of grade III or larger.

Completeness of Tumor Removal

The extent of tumor resection was defined as total when resection is complete and as near total when the wall of cystic component, tumor capsule, or tiny remnants overlying FN or major vessels of CPA are left behind to avoid damaging these structures. Even if there was no evidence of tumor residue on postoperative MRI, it was considered near-total removal if the surgeon thought that a tiny remnant attached to cranial nerves, major vessels, or brainstem was left. Subtotal removal refers to a minor residue that is left because the tumor was too adherent to the FN and there was no distinguishable cleavage plane that could be followed, providing a harmless dissection without damaging the nerve. Partial removal refers to a resection that is stopped to leave behind a significant residue because of changes in vital signs or major bleeding.

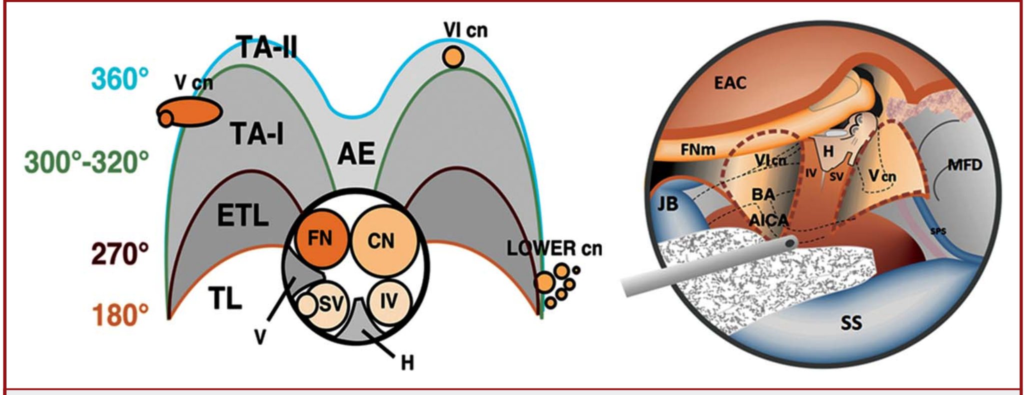

FIGURE 2. *Schematic views showing the extension of bone drilling around the internal auditory canal in the enlarged translabyrinthine approach with transapical extension. AE, anterior wall of the internal auditory canal; AICA, anteroinferior cerebellar artery; BA, basilar artery; CN, cochlear nerve; EAC, posterior wall of the external auditory canal; ETL, enlarged translabyrinthine approach; FN, facial nerve; FNm, mastoid segment of the facial nerve; H, horizontal crest; IV, inferior vestibular nerve; JB, jugular bulb; Lower cn, lower cranial nerves; MFD, middle fossa dura; SPS, superior petrosal sinus; SS, sigmoid sinus; SV, superior vestibular nerve; TA-I, transapical extension type I; TA-II, transapical extension type II; TL, classic translabyrinthine approach; V, vertical crest; Vcn, trigeminal nerve; VI cn, abducens nerve.*

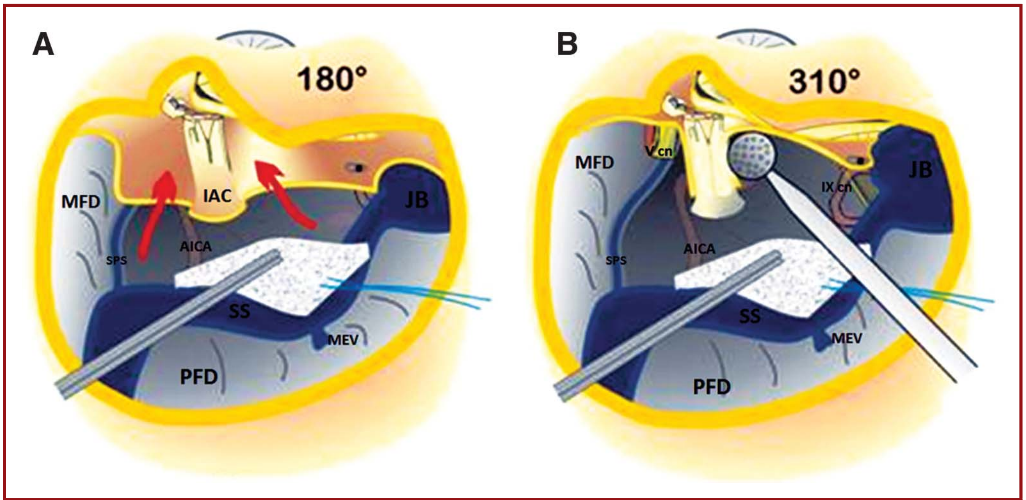

FIGURE 3. *Schematic views showing the difference between conventional translabyrinthine approach (TLA; A) and enlarged TLA with transapical extension type I (B). AICA, anteroinferior cerebellar artery; IAC, internal auditory canal; JB, jugular bulb; MEV, mastoid emissary vein; MFD, middle fossa dura; PFD, posterior fossa dura; SPS, superior petrosal sinus; SS, sigmoid sinus; Vcn, trigeminal nerve; IX cn, glossopharyngeal nerve.*

FN Function

The House-Brackmann (HB) scale was used to evaluate the FN function before surgery and during follow-up.[11] Good FN outcome was defined as HB grade I or II, acceptable outcome as HB grade III or IV, and poor outcome as HB grade V or VI.

CSF Leakage

A patient was considered to have CSF leakage when a colorless fluid flow was noticed through the nose (rhinoliquorrhea), the ear (otoliquorrhea), or the wound (cutaneous liquorrhea). In addition, retroauricular subcutaneous CSF collections were taken into account.

RESULTS

A χ^2 test was used to test the statistical significance of any difference.

Patient Characteristics

A total of 1865 of 2472 patients met the eligible criteria for the present study. They consisted of 886 (47.50%) male and 979 (52.49%) female patients, ranging in age from 10 to 83 years (mean, 50.39 ± 10.08 years). The tumors ranged in size from 0 cm (purely intracanalicular lesion) to 5.5 cm, with a mean of 1.8 ± 0.97 cm. It is worth mentioning that despite the fact that the number of large VSs operated on at our center has increased over the years thanks to the expertise gained by the senior author (M.S), the mean size showed a downward trend, dropping from 2.2 cm in the late 1980s to 1.8 cm in 2009. This could be explained by a prompt diagnosis thanks to a higher degree of clinical suspicion and the use of MRI. There was no predominance regarding the side of the lesion, with 926 (49.65%) located on the right and 939 (50.34%) on the left. The median follow-up was 5.7 years (range, 12-127 months).

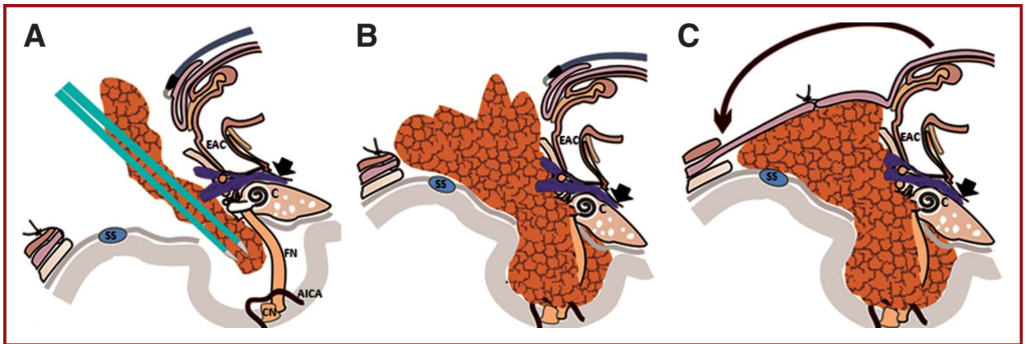

FIGURE 4. *Schematic view showing the closure technique. The periosteum is pushed within the middle ear cleft (A), and then long fat strips are introduced in the cerebellopontine angle (B) and the musculoperiosteal layer is closed tightly (C). The arrow indicates the periosteum clogging the Eustachian tube. AICA, anteroinferior cerebellar artery; C, cochlea; CN, cochleovestibular nerve; EAC, external auditory canal; FN, facial nerve; SS, sigmoid sinus.*

Tumor Control

Complete removal was achieved in 1722 cases, whereas tumor removal was incomplete in 143 cases. In 5 patients, total resection was attained in 2 stages, mainly because of major bleeding and vital sign changes during the first surgery. The second stage was performed within 6 months of the primary surgery. Incomplete tumor removal occurred more often in larger VSs. In patients who had incomplete removal, mean tumor size (2.9 ± 0.64 cm) was significantly larger than in those who had total resection (1.73 ± 0.99 cm). Absence of cleavage plane and adherence of the tumor to surrounding critical structures were the main reasons for incomplete resection to preserve FN integrity and to prevent damage to vital neurovascular structures such as cerebellar arteries and brainstem. In rare cases, tumor exeresis was interrupted because changes in vital signs occurred during dissection of the tumor from the brainstem. Recurrences were seen in 1 patient, whereas of the 143 patients who had incomplete removal, only 8 showed evidence of tumor regrowth on follow-up MRI. Among these 8 patients, 4 had minimal regrowth without any clinical impact and are still under watchful neuroradiological monitoring, and 4 had sizable growth of their residual tumors, which needed further treatment. Two patients underwent a second surgery, with total removal in 1 case and near-total removal in the other; the other 2 patients were treated by stereotactic radiosurgery because they refused surgery.

FN Function

Considering only previously untreated patients with normal preoperative facial function, good FN outcome (HB grade I and II) was reached in 1047 of 1742 patients (59.87%) regardless of anatomic preservation. As shown in Table 1, FN outcome after tumor removal depends significantly on tumor size. The larger the tumor was, the worse the facial function was.

In 81 patients (4.64%), anatomic continuity of FN could not be preserved. The mean tumor size (2.7 ± 0.72 cm) was significantly larger in these patients than in those with anatomically preserved FN ($P < .001$). Of these patients, 19 had end-to-end anastomosis, 52 had FN reanimation by use of sural nerve graft, and 10 had no reconstruction during the same stage because the proximal stump of the severed FN was too short. Among the last group, 7 patients accepted an additional nerve reconstruction procedure and had hypoglossal-FN anastomosis. In the 78 patients who underwent a reconstruction procedure, 46 recovered to HB grade III, 11 to HB grade IV, and 4 to HB grade V; 17 did not show any recovery.

Surgical Complications

Table 2 shows the frequency of the different complications encountered after ETLA for VS removal.

CSF Leakage and Meningitis

Sixteen of 1865 patients (0.85%) had CSF leakage. Nine presented with rhinoliquorrhea, 5 with cutaneous liquorrhea, 1 with retroauricular subcutaneous CSF collection, and 1 with otoliquorrhea. Six patients were successfully treated by compressive dressing with an additional lumbar drainage in 2, whereas the 10 remaining patients (0.53%) needed revision surgery with exploration and further sealing of patent air cells. There was no significant correlation between tumor size and occurrence of CSF leak. Only 2 patients (0.10%) presented with symptoms of meningitis during the postoperative period, and both of them had CSF leakage. A CSF sample confirmed the diagnosis in both cases. The patients were treated with intravenous antibiotics with good recovery.

Intracranial Hemorrhage and Mortality

Postoperative bleeding was encountered in 15 patients (0.80%). Almost all cases of hemorrhage occurred in the first postoperative night, most commonly within the first 8 hours, and presented as a worsening of consciousness with focal neurological signs. Six patients had CPA hematomas. Four of them needed urgent revision surgery consisting of hematoma evacuation, whereas the other 2 were managed conservatively because they had only neurological deficit without impairment of consciousness. All of them fully recovered after suitable rehabilitation. Three patients had intracerebellar hematoma, extending into the brainstem in 1 case. They were managed conservatively in the intensive care unit. Two

TABLE 1. Facial Nerve Outcome in Patients Who Had Primary Surgery at Gruppo Otologico With Normal Preoperative Facial Function[a]

Size	HB Grade I, n (%)	HB Grade II, n (%)	HB Grade III, n (%)	HB Grade IV, n (%)	HB Grade V, n (%)	HB Grade VI, n (%)	Total, n
Grade 0 (intrameatal)	165 (82.5)	20 (10)	13 (6.5)	2 (1)	0 (0)	0 (0)	200
Grade I (1-10 mm)	341 (73.33)	45 (9.67)	71 (15.26)	7 (1.50)	1 (0.21)	0 (0)	465
Grade II (11-20 mm)	227 (44)	71 (13.75)	163 (31.58)	18 (3.48)	7 (1.35)	30 (5.81)	516
Grade III (21-30 mm)	85 (23.28)	46 (12.60)	176 (48.21)	28 (7.67)	9 (2.46)	21 (5.75)	365
Grade IV (31-40 mm)	28 (19.85)	7 (4.96)	55 (39)	17 (12.05)	4 (2.83)	30 (21.27)	141
Grade V ≥ 41 mm	6 (10.90)	2 (3.63)	30 (54.54)	3 (5.45)	3 (5.45)	11 (20)	55
Total	852 (48.90)	191 (10.96)	508 (29.16)	75 (4.30)	24 (1.37)	92 (5.28)	1742

[a]HB, House-Brackmann.

TABLE 2. Postoperative Complications[a]

Complication	N	%	Comment
Abdominal subcutaneous hematoma	65	3.48	
Retroauricular subcutaneous hematoma	14	0.75	
CSF leakage	16	0.85	9 Rhinoliquorrhea, 5 cutaneous liquorrhea, 1 subcutaneous CSF collection, and 1 otoliquorrhea; only 10 patients (0.53%) required revision surgery
Meningitis	2	0.10	1 Cutaneous CSF leak and 1 rhinorrhea after 5 wk
Cerebellopontine hematoma	6	0.32	4 Needed urgent revision surgery and 2 were managed conservatively
Intracerebellar hematoma	3	0.16	In 1 case, the hematoma extended into brainstem; all had conservative treatment; 1 died
Brainstem hematoma	2	0.10	1 Died and 1 had hemiplegia
Supratentorial hematoma	3	0.16	All had chronic subdural hematomas; only 1 needed surgical evacuation
Subarachnoid hemorrhage	1	0.05	Invading the fourth ventricle and leading to hydrocephalus needing external ventricular drainage
Hemiparesis	1	0.05	Secondary to an intrapontine hematoma
Lower cranial nerves palsy	8	0.42	2 Transient and 6 with good compensation
Sixth cranial nerve palsy	10	0.53	8 Transient
Lateral sinus thrombosis	1	0.05	Total recovery after treatment with heparin
Death	2	0.10	Both are related to postoperative bleeding
Cerebellar ataxia	13	0.69	Only 1 case had cerebellar infarct
Aphasia	1	0.05	Origin unknown
Cognitive impairments	1	0.05	
Keratitis	2	0.10	

[a]CSF, cerebrospinal fluid.

patients recovered completely without any neurological sequelae, and the 1 patient whose cerebellar hematoma extended into brainstem died after 1 week. Two patients had purely intrapontine hematomas, presenting as loss of consciousness in 1 case and as hemiplegia in the other case. Both were managed conservatively. One died 10 days later, and 1 has kept a mild hemiparesis with good autonomy. One patient had subarachnoid hemorrhage invading the fourth ventricle, which led to an obstructive hydrocephalus. This required ventricular drain placement, and the patient recovered well. Three patients had supratentorial chronic subdural hematomas; 1 of these patients required surgical treatment. All patients recovered completely without neurological sequelae. There were only 2 deaths in this series (0.10%); both were related to postoperative intracranial bleeding, as mentioned above.

Neurological Sequelae

One patient had a mild hemiparesis related to a postoperative intrapontine hematoma, as mentioned previously. Eight patients (0.42%) had lower cranial nerve palsies postoperatively. They were transient in 2 patients and well compensated after rehabilitation in the remaining 6 patients with no further disability. Ten patients (0.53%) presented with postoperative diplopia related to sixth cranial nerve palsy that was transient in 8 cases. Thirteen patients (0.69%) persisted with a cerebellar ataxia. Postoperative MRI showed evidence of cerebellar infarct in one of these patients. One patient had transient aphasia of unexplained origin, and another patient had some cognitive impairments.

Wound Problems

The most frequent complication of the present series was subcutaneous abdominal hematoma at the site where adipose tissue was harvested, occurring in 65 cases (3.48%). Retroauricular subcutaneous hematoma occurred in 14 patients (0.75%) and required wound revision in 8 patients.

Other Complications

Two patients with FN palsy after surgery developed ocular keratitis despite the use of prophylactic measures. One patient had a lateral sinus thrombosis revealed by visual field defect occurring 1 month after surgery. It was managed with heparin treatment, and the patient experienced complete recovery.

DISCUSSION

If the pioneers dealing with VS in the beginning of the previous century were asked how this tumor makes them feel, their answer would likely be powerless. Thanks to the considerable advances in diagnostic tools and microsurgery in the last decades, total tumor removal with minimal morbidity became achievable in most cases. Tables 3 and 4 show the surgical results of the major series published in the English literature.

Tumor Control

In the present study, total removal was reached in 92.33% of cases, and incomplete resection was performed in 143 patients.

TABLE 3. Facial Nerve Outcome in Major Series Published in the English Literature[a]

Reference	Total Cases, n	TLA Cases, n	Mean Size, cm	Total Removal, n (%)	Anatomic Conservation of FN, n (%)	Postoperative FN Outcome, n (%) HB Grade I	HB Grade II	HB Grade III	HB Grade IV	HB Grade V	HB VI
Glasscock et al,[24] 1986	616 (568 VS)	436	2.33 (Considering only TLA)	610[b] (99.02)	373 (85.55)	Ns	Ns	Ns	Ns	Ns	Ns
Thomsen et al,[28] 1991	504	504	369 Tumors ≥ 2.0	495 (98.21)	488 (96.82)	284 (57.48)	60 (12.14)	40 (8.09)	26 (5.26)	27 (5.46)	57 (11.53)
Ekvall et al,[23] 1991	261[c]	261	98 Tumors ≥ 3.0	253 (96.93)	Ns	133 (54.28)[d]	28 (11.42)	45 (18.36)	16 (6.53)	5 (2.04)	18 (7.34)
Ebersold et al,[22] 1992	256	Only RS	99 Cases ≤ 2.0, 2.1 ≤ 117 cases ≤ 4.0, 40 cases > 4.0	249 (97.26)	237 (92.57)	84 (52.17)[e]	19 (11.80)	24 (14.90)	13 (8.07)	14 (8.69)	7 (4.34)
Samii and Matthies,[26] 1997	1000	Only RS	Ns	979 (97.9)	929 (93.93)	470 (50.59)[f]	120 (12.91)	140 (15.06)	60 (6.45)	100 (10.76)	39 (4.19)
Mass et al,[25] 1999	258	258	1.86 ± 1.11	254 (98.44)	Ns	162 (62.79)	34 (13.17)	30 (11.62)	16 (6.20)	7 (2.71)	9 (3.48)
Sluyter et al,[27] 2001	120	120	All tumors ≥ 2.0	110 (91.66)	97 (80.83)	54 (HB I and II) (56.25)[g]		13 (13.54)	16 (16.66)	5 (5.20)	8 (8.33)
Wiet et al,[18] 2001	500	370	2.2 ± 1.1	Ns	Ns	306 (67.84)	40 (8.86)	47 (10.42)	15 (3.32)	10 (2.21)	33 (7.31)
Darrouzet et al,[13] 2004	400	229	Ns; 239 patients > 2.0	390[b] (97.5)	384[b] (96)	283 (HB I and II) (70.75)		97 (HB III and IV) (24.25)		20 (HB V and VI) (5)	
Brackmann et al,[12] 2007	512	512	2.4	484 (94.53)	500 (97.65)	265 (67.6)[h]	52 (13.26)	32 (8.16)	28 (7.14)	3 (0.76)	12 (3.06)
Present study	1865	1865	1.8 ± 0.97	1722 (92.33)	1661 (95.35)[i]	852 (48.90)[i]	191 (10.96)	508 (29.16)	75 (4.30)	24 (1.37)	92 (5.28)

[a]FN, facial nerve; HB, House-Brackmann; Ns, not specified; RS, retrosigmoid; TLA, translabyrinthine approach.
[b]Results including all cases, not only those operated through TLA.
[c]Including 15 cases of cerebellopontine angle meningioma, 3 FN schwannoma, and 1 jugular foramen schwannoma.
[d]FN outcome excluding 16 patients with preoperative FN dysfunction and 3 patients with FN schwannoma.
[e]Functional outcome was assessed in 161 patients with at least 1 year of follow-up.
[f]FN outcome reported for 929 cases of 1000, excluding those with anatomically severed FN.
[g]Facial function outcome reported in 96 patients with anatomically preserved FN.
[h]FN outcome was assessed in 392 patients.
[i]FN results reported in 1742 previously untreated patients with normal preoperative nerve function.

Comparable rates of total removal ranging from 91.66% to 99.02% (Table 3) have been reported in the literature. The most limiting factors of total removal were absence of cleavage plane and adherence of the tumor to critical neurovascular structures. This has also been reported by other authors.[12,13] Patients who had incomplete resection were older (mean age, 63.42 ± 9.43 years) and had larger tumors (mean size, 2.9 ± 0.64 cm) than those who had total removal (mean age, 50.39 ± 10.08 years; mean size, 1.8 ± 0.97 cm). It should also be noted that although 8 of the 143 patients who had incomplete resection showed evidence of regrowth on serial control MRI, only 4 (2.79%) needed further treatment for tumor regrowth. Two patients had a second operation through the same approach. One of these cases had total removal, whereas the other one had near-total removal. The other 2 patients underwent stereotactic radiosurgery for residual tumor, and they have not yet shown

TABLE 4. Surgical Results of the Major Series Published in the English Literature[a]

Reference	Total Cases, n	TLA Cases, n	Mean Size, cm	Total Removal, n (%)	CSF Leak, n (%)	Meningitis, n (%)	Intracranial Bleeding, n (%)	Non–VII/VIII Affected CN, n (%)	Brain Infarcts, n (%)	Cerebellar Ataxia, n (%)	Deaths, n (%)
Glasscock et al,[24] 1986	616 (568 VS)	436	2.33 (Considering only TLA)	610[b] (99.02)	49 (11.23)	33[b] (5.35)	4[b] (0.64)	20[b] (3.24)	2[b] (0.32)	Ns	4[b] (0.64)
Thomsen et al,[28] 1991	504	504	369 Tumors ≥ 2.0	495 (98.21)	45 (8.92)	15 (2.97)	7 (1.38)	9 (1.78)	Ns	20 (3.96)	9 (1.78)
Ekvall et al,[23] 1991	261[c]	261	98 Tumors ≥ 3.0	253 (96.93)	7 (2.68)	2 (0.76)	0	3 (1.14)	Ns	1 (0.38)	1 (0.38)
Ebersold et al,[22] 1992	256	Only RS	99 Cases ≤ 2.0, 2.1 ≤ 117 cases ≤ 4.0, 40 cases > 4.0	249 (97.26)	28 (10.93)	2 (0.78)	1 (0.39)	8 (3.12)	0	5 (1.95)	2 (0.78)
Samii and Matthies,[26] 1997	1000	Only RS	Ns	979 (97.9)	92 (9.2)	30 (3)	22 (2.2)	55 (5.5)	7 (0.70)	350 (35)	11 (1.1)
Mass et al,[25] 1999	258	258	1.86 ± 1.11	254 (98.44)	20 (7.75)	10 (3.87)	0	1 (0.38)	1 (0.38)	1 (0.38)	0
Sluyter et al,[27] 2001	120	120	All tumors ≥ 2.0	110 (91.66)	24 (20)	11 (9.2)	1 (0.80)	12 (10)	Ns	Ns	1 (0.83)
Slattery et al,[31] 2001	1687	1224	2.0 ± 1.1	1656 (98.16)	159 (9.42)	25 (2.04)	15 (1.22)	Ns	4 (0.32)	Ns	2 (0.16)
Darrouzet et al,[13] 2004	400	229	Ns; 239 patients > 2.0	390[b] (97.5)	52[b] (13)	18 (7.86)	2[b] (0.87)	15[b] (3.75)	4[b] (1.74)	Ns	2[b] (0.50)
Brackmann et al,[12] 2007	512	512	2.4	484 (94.53)	28 (5.5)	3 (0.60)	7 (1.36)	Ns	5 (0.97)	Ns	0
Present study	1865	1865	1.8 ± 0.97	1722 (92.33)	16 (0.85)	2 (0.10)	15 (0.80)	18 (0.96)	1 (0.05)	13 (0.69)	2 (0.10)

[a]CN, cranial nerve; FN, facial nerve; HB, House-Brackmann; Ns, not specified; RS, retrosigmoid; TLA, translabyrinthine approach.
[b]Results including all cases, and not just those operated through TLA.
[c]Including 15 cases of cerebellopontine angle meningioma, 3 FN schwannomas, and 1 jugular foramen schwannoma.

any further growth. From the present study, it seems that the tumor remnants left behind are unlikely to grow because only 8 patients (5.59%) showed evidence of regrowth. This rate is comparable to that of failure after radiosurgery. In a recent review of modern stereotactic radiosurgery results, Murphy and Suh[14] reported a progression-free survival ranging from 92% to 100%. But even in these still-growing tumors, the growth rate was very slow because only 4 patients (2.79%) had a sizable growth needing further treatment. Such observations have also been reported by El-Kashlan et al,[15] who did not see any evidence of regrowth in patients who had incomplete resection with > 98% of the tumor excised. Given the shorter life expectancy in older patients and the low risk of recurrence, opting for incomplete resection to preserve neurological functions and quality of life is an attractive alternative that should be considered in patients of advanced age and with severe comorbidity.

FN Function

Because FN outcome is one of the crucial factors that affect quality of life, preservation of its motor function is still the major concern when proposing surgical treatment to patients with VS. Injury to FN during VS resection can result in a profound cosmetic defect. This may necessitate subsequent surgical procedures that increase overall healthcare costs associated with the initial surgical intervention.[16] Thanks to the use of intraoperative neurophysiological monitoring and improvements in microsurgical techniques, anatomic preservation of FN is now achievable in most cases.[17] Despite the fact that anatomic conservation of FN was reached in 1661 previously untreated patients, good outcome (HB grade I and II) was attained only in 1043 of them (62.79%). This outcome was not surprisingly worse in larger tumors than in the smaller ones, as reported by other authors.[12,13,16,18,19] In our series, good outcome decreased significantly in tumors > 20 mm. Tumor adherence to FN requires much more handling to achieve complete removal. This could be the reason for the lower functional preservation rate seen in the large tumor group. Facial nerve results were also analyzed depending on patient age. Although no significant difference was noticed in small tumors, in large tumors, better outcome was achieved in older patients. Such a relationship was also reported by Sughrue et al,[16] who noticed that younger patients had a worse FN preservation rate compared with older patients (71% vs 84%; $P < .001$). Perhaps this could be explained by the goal of this surgery because the concept of priority of neurological function over complete resection was more easily adopted in old patients. Our philosophy is to achieve complete resection in younger patients because they have a longer life expectancy and likely higher risk of growth resumption. Over the years, we have made some refinements in the classic TLA to minimize procedure-related morbidity. For FN identification, we use a personal technique with the superior ampullary nerve as a landmark.[6] In our experience and as reported by Sampath et al,[20] the FN is commonly located anterior to the tumor and is hidden by it, especially in larger VS. Transapical extension, by removing the bone surrounding the IAC, provides better visual control of tumor anterior boundaries and enables excision in safer conditions. Although these refinements allowed us to shorten the duration of surgery and to diminish the complications rate, no impact on FN results was noticed. Dissection of the tumor capsule from FN may interrupt microvascular blood supply and lead to postoperative loss of function; we believe that the most limiting factor of FN preservation should be tumor adherence, which is stronger in large tumors and in cystic tumors.[21] Good FN outcome has been reported in 56.25% to 80.86% of cases after VS surgery[12,13,18,22-28] (Table 3). This difference in outcomes is related to the way of collecting (clinical evaluation, telephone interview, or questionnaire) and reporting results.[19] To reduce subjective variability when assessing postoperative facial function, we recommend the use of photographic documentation during follow-up. Another factor of bias is the way tumor size is measured (including the intrameatal component) and the grading system used to group together tumors of different size. To overcome this problem, we recommend the use of the grading system approved in Acoustic Neuroma Consensus on Systems for Reporting Results held in 2001 in Tokyo.[10]

Surgical Complications

The mortality of VS surgery dropped from rates as high as 80% in the early 20th century to < 1% nowadays.[2,29] Surgery for VS has evolved from a lifesaving surgery to functional microsurgery. As a result, although completeness of resection is the primary goal of surgery, it should not be achieved at the cost of neurological functions. Table 4 shows the surgical complications of some of the major series published in English literature.

CSF Leakage and Meningitis

Cerebrospinal fluid leakage still has a significant incidence after VS surgery, ranging from 2.68% to 20% (Table 4). Until 1993, the overall incidence of CSF leak at our institution was 6.9%. Given this unacceptably high rate, we decided to change the surgical method of wound closure in an attempt to lower its occurrence.[9] As a result, the CSF leakage rate dropped dramatically to < 1% and has remained unchanged =.[30] To the best of our knowledge, with only 16 patients (0.85%) having had CSF leakage, we have the lowest rate ever reported in the English literature. Despite being suggested by other authors,[13,31] no significant correlation between tumor size and occurrence of CSF leak was noticed in our experience.[30,32] Only 2 cases (0.10%) of meningitis occurred during the postoperative course, and both were related to a CSF leakage (cutaneous liquorrhea in 1 patient and rhinoliquorrhea in the other). This extremely low rate is not unrelated to the low incidence of CSF leakage. A strong correlation between CSF leakage and incidence of meningitis was reported by Slattery et al.[31] They noticed that meningitis occurred more frequently in patients with CSF leak (9.7%) than in those without CSF leak (1%). Meningitis was also found to occur at a higher rate in larger tumors than in smaller ones.[13,31] One suggestion given to explain the higher rate of meningitis in larger tumors was the longer duration of surgery, which is correlated with the risk of nosocomial complications.[13]

Intracranial Hemorrhage and Mortality

Intracranial postoperative bleeding is the most dreaded complication after VS surgery. In this study, intracranial hemorrhage occurred in 15 patients (0.80%) and was the exclusive cause of the 2 deaths (0.10%) in our series. Except for 3 delayed supratentorial subdural hematomas, all postoperative hemorrhages occurred in the early postoperative course, within the first 12 hours, and presented as a worsening of consciousness with focal neurological signs. Therefore, we consider that early awakening after the operation is crucial to recognize symptoms related to intracranial bleeding in time and to provide early treatment for such life-threatening complications. In the most critical cases, the wound should be opened under sterile conditions at the bedside to relieve the raised intracranial pressure quickly. This will create a safety valve, preventing further pressure on the brainstem. In the present study, no postoperative bleeding occurred in the last 551 operated patients. We strongly believe that the very low prevalence of certain complications is directly related to the surgical technique. The exposure provided by the classic TLA is limited for large tumors because the area anterior to the porus acusticus, the superior extent of the tentorium, and the region inferior to jugular bulb are inaccessible to direct vision.[24] Development of the transapical extension in combination with the enlarged TLA has allowed us to improve tumor exposure and enabled direct visualization of areas that were once considered blind zones. This prevents blind dissection and inadvertent damage to critical neurovascular structures intimately attached to the tumor capsule. Bloodless surgery is also of paramount importance because the tumor is usually surrounded by an arachnoid plane that must be preserved because it could be very helpful in dissecting tumor capsule from the adjacent structures. Otherwise, if this natural cleavage plane becomes indistinguishable because the operating field is contaminated with blood, preserving neurovascular structures will be a very difficult task. It should be remembered that veins crossing the tumor surface can generally be coagulated if significant bleeding arises or if their preservation is not possible. If needed, even the Dandy vein could be coagulated without any sequelae. However, coagulation of veins running over the brainstem must be avoided because it may lead to deleterious effects with likely hemorrhagic infarction. In those cases in which bleeding from veins overlying the pons arises, we recommend the use of Surgicel with slight packing. Care should be taken at the end of the procedure to ensure meticulous hemostasis. For that, the Valsalva maneuver and raise of arterial blood pressure are systematically used before closure to search for an occult bleeding.

Neurological Complications

The ETLA has the advantage of not requiring cerebellar retraction. Therefore, a single case of cerebellar infarct was reported in the present study, and only 0.69% of patients had cerebellar-related gait disturbance. Eight patients (0.42%) kept a definitive cranial nerve palsy (6 had lower cranial nerve palsy, and 2 had a sixth cranial nerve palsy), which is, to the best of our knowledge, the lowest rate of non–VII/VIII cranial nerve palsy.

Wound Problems

The most frequent complication of the present series was by far wound subcutaneous hematomas at both abdominal and retro-auricular incisions. A possible explanation is that fat tissue harvesting and skin closure are done by young clinical fellows.

CONCLUSION

Over the years, we have introduced some technical modifications to the TLA that allowed us to reduce the mortality rate to < 1% with minimal morbidity. Identifying FN by using the ampullary nerve as a landmark rather than the Bill bar, lowering the high jugular bulb, and extending bone removal around and anterior to the IAC (transapical extension) were the major refinements added to the original technique. Preservation of FN is still the major concern of VS surgery, even in very skilled hands, and represents the crucial factor affecting postoperative quality of life. Because tumor size remains the main factor influencing FN outcome, the next step in the VS saga should focus on early diagnosis and treatment.

Disclosures

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COMMENTS

This is an important article reviewing extensive experience with a modification of the translabyrinthine approach. The authors describe technical modifications that were useful for them in overcoming some limitations of the original translabyrinthine approach. The specific modifications these authors describe, including more anterior exposure with bone removal, use of the superior canal ampullary nerve for facial nerve identification, and decompression of the jugular bulb, are modifications that can be variably applied, depending on the tumor size, patient anatomy, and patient health factors. The main value of this landmark article is an appreciation of the versatility of the translabyrinthine approach for tumors of all sizes with excellent outcomes. This article eloquently refutes the oft-repeated, albeit erroneous, misconception that the role of the translabyrinthine approach is limited to small tumors. The authors provide precise documentation with impressive outcomes in tumors of all sizes from intracanalicular to massive lesions. This surgical experience of 1865 patients by a single surgeon in a 22-year period is an important addition to the literature.

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The authors present one of the large published series of patients with surgically treated vestibular schwannomas. They review the results after removal of vestibular schwannomas through the enlarged translabyrinthine approach, which is a widening of the classic translabyrinthine approach. Considering the current debate on the optimal management of such patients, the wide distribution of radiosurgical facilities, and the overwhelming number of publications on radiosurgery, studies on the long-term outcome of surgery in experienced hands are more than welcomed. The present study is further proof that surgical removal of vestibular schwannomas is the only curative treatment and can be achieved with low morbidity rates and good functional outcome. Total removal was achieved in 92.3% of the cases in the series. In 7.7%, tumor removal was incomplete owing to the absence of cleavage plane and adherence of the tumor to surrounding critical structures. Anatomic preservation of facial nerve was achieved in 95.4%, and House-Brackmann grade I or II was reached 59.9%. The mortality rate was 0.1% and the surgical complication rate was low. Recurrences after complete tumor removal were seen in only 1 patient. In 8 patients who had incomplete removal, follow-up magnetic resonance imaging showed tumor regrowth, but only 4 tumors had to be reoperated.

Despite our admiration of the authors' achievements, there is 1 important point of disagreement. Modern vestibular schwannoma surgery should be function preserving. Although facial nerve preservation was major concern in the past decades, nowadays hearing preservation is the main challenge. The authors adopted the hearing-destructive enlarged translabyrinthine approach not only in patients with bad preoperative hearing but also in all patients with tumors exceeding 1.5 cm and those in whom the tumor extended laterally into the fundus of internal auditory canal. Taken into account the facts that the series includes intracanalicular tumors and that the mean tumor size was 1.8 cm, it is obvious that in many patients there was a chance for functional hearing preservation. Moreover, hearing preservation in patients with large and even giant vestibular schwannomas is not an exception.[1-4]

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The authors provide a summary of a large series of vestibular schwannomas, primarily by one surgeon, emphasizing their experience with the translabyrinthine approach. They provide a local utilized classification of extent of exposure that facilitates discussion of surgical technique. This is accompanied by a good set of illustrations showing their understanding of the surgical management of this disease. Though the exact application of these principles probably never occurs in their pure form due to individual anatomic variation, they provide a good framework for trainees to think about the operation.

Although cases have been collected for this report since 1987 the maximum follow-up is just over 10 years. Large collections of cases such as this can be very useful for more arcane statistics such as late (eg, >10 year) recurrences and this opportunity appears to have been missed here.

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