

## OTOLOGY

# Surgical treatment of sporadic vestibular schwannoma in a series of 1006 patients

## *Trattamento chirurgico degli schwannomi vestibolari: risultati su una serie di 1006 pazienti*

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## SUMMARY

The management of sporadic vestibular schwannoma (VS) has evolved in the last decades. The aim of this study was to analyse the evolution in surgical outcomes of VSs operated by a neurotological team between 1990 and 2006 by different approaches. A monocentric retrospective review of medical charts of 1006 patients was performed. In order to assess eventual changes and progress, the 17-years period was divided in three periods, each one comprehending 268 VS (1990-1996), 299 VS (1997-2001), and 439 VS (2002-2006). Mean follow-up was  $5.9 \pm 2.4$  years. Overall, complete VS removal was achieved in 99.4% of cases. Mortality rate was 0.3%, meningitis and CSF leaks were observed in 1.2% and 9% of the cases, respectively. CSF leakage decreased from 11.6% to 7.1% between the first and last period ( $p < 0.01$ ) as well as revision surgery from 3.4% to 0.9% ( $p < 0.05$ ). Facial nerve was anatomically preserved in 97.7% of cases. At one year, a good facial nerve function was observed in 85.1% of patients (grade I and II of House-Brackmann grading scale), which ranged between the first and last period from 78.4% to 87.6% ( $p < 0.05$ ). At one year, hearing preservation was obtained in 61.6% of patients, which increased from the first period to the last one from 50.9% to 69.0% ( $p < 0.05$ ) (class A+B+C from the AAO-HNS classification). Useful hearing (class A+B) was observed in 33.5% of cases overall, with 21.8% and 42% in the first and last period, respectively ( $p < 0.01$ ). Surgical outcomes of sporadic vestibular schwannoma have improved concerning facial nerve function outcomes, hearing preservation and cerebrospinal fluid (CSF) leaks, mainly due to the neuro-otological team's experience. Functional results after complete microsurgical removal of large VS depend on experience gained on small VS removal.

KEY WORDS: Facial nerve • Vestibular schwannoma • Translabyrinthine • Hearing levels

## RIASSUNTO

*La gestione dello schwannoma vestibolare (SV) sporadico si è gradualmente evoluta negli ultimi decenni. Lo scopo di questo studio è di analizzare l'evoluzione negli esiti chirurgici dell'exeresi di queste lesioni, realizzata da un team neurotologico tra il 1990 e il 2006, attraverso differenti approcci. È stata eseguita una revisione retrospettiva monocentrica dei dati clinici di 1006 pazienti. Al fine di valutare eventuali modifiche e progressi, il periodo di 17 anni è stato diviso in tre periodi, ciascuno comprendente rispettivamente 268 SV (1990-1996), 299 SV (1997-2001), e 439 SV (2002-2006). Il follow-up medio è stato di  $5,9 \pm 2,4$  anni. Complessivamente l'asportazione totale è stata ottenuta nel 99,4% dei casi. Il tasso di mortalità è stato dello 0,3%, la meningite e la perdita di liquido cefalo rachidiano (LCR) sono stati osservati nel 1,2% e il 9% dei casi, rispettivamente. La frequenza della perdita di LCR è diminuita dal 11,6% al 7,1% tra il primo e dell'ultimo periodo ( $p < 0,01$ ) e la revisione chirurgica dal 3,4% al 0,9% ( $p < 0,05$ ). Il nervo facciale è stato anatomicamente conservato nel 97,7% dei casi. Ad un anno, una buona funzione del nervo facciale è stata osservata nel 85,1% dei pazienti (I e II grado House-Brackmann), con una variazione tra il primo e l'ultimo periodo che andava dal 78,4% al 87,6% ( $p < 0,05$ ). Ad un anno post-operatorio la conservazione dell'udito è stata ottenuta nel 61,6% dei pazienti, passando dal 50,9% del primo periodo, al 69,0% del periodo più recente ( $p < 0,05$ ) (classe A + B + C dalla classificazione AAO-HNS). L'udito utile (classe A + B) è stato conservato nel 33,5% dei casi complessivamente, con percentuali comprese tra il 21,8% e 42% nel primo e nell'ultimo periodo rispettivamente ( $p < 0,01$ ). Gli esiti chirurgici dell'asportazione dello schwannoma vestibolare sporadico sono migliorati negli anni per quanto riguarda i risultati funzionali del nervo facciale, la conservazione dell'udito, le perdite di liquido cefalorachidiano, principalmente grazie all'esperienza del team neurotologico. I risultati funzionali dopo la rimozione microchirurgica completa SV di grandi dimensioni dipendono dall'esperienza maturata sulle lesioni di piccole dimensioni.*

PAROLE CHIAVE: Nervo facciale • Schwannoma vestibolare • Translabirintico • Udito

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## Introduction

Complete microsurgical excision of sporadic vestibular schwannoma (VS) has been advocated for all tumour sizes, up to the beginning of this century. Because of the development of magnetic resonance imaging (MRI) techniques, which have been easier to obtain, a wait and scan policy was introduced in the early 1990s<sup>1</sup>. Since then, the introduction of radiotherapy in stereotaxic conditions, mainly by gamma-knife, invigorates the debate concerning the microsurgical removal of small and middle-sized VS, especially in the elderly when VSs are progressive. Besides, radiosurgery has become more popular as far as the doses have been reduced to limit the toxic effects of radioactive agents on neurological structures, and it has been proposed, in case of large VS, to reduce the posterior fossa extension of the tumour by a partial microsurgical excision before irradiating the remaining tumour<sup>2</sup>.

Nevertheless, recent studies have described advances in surgical techniques and devices, which in association with the improvement of surgeon's experience may have led to a gradually decreasing surgical mortality and morbidity. Hence, the modern surgical goals of sporadic VS have changed to achieve higher complete tumour removal, with higher rates of facial nerve (FN) function and hearing level preservation, lower mortality and neurological morbidity incidence<sup>3-8</sup>.

Good postoperative outcomes depend on several factors including tumour size, surgical approaches, intraoperative nerve monitoring, cranial nerve displacement pattern and tumour adherence to neurological structures, in addition to surgical experience<sup>4-12</sup>. However, few authors have reviewed surgical outcomes of large series of more than 500 cases<sup>4-8,13</sup>. The aim of this study is to report the surgical outcomes in a large series of more than 1000 sporadic VS operated by the same neuro-otological team over a 17-year period.

## Materials and methods

A monocentric retrospective review was performed on medical charts of 1006 consecutive patients operated for sporadic VS removal between January 1990 and December 2006. Patients with neurofibromatosis Type II (NF2) were excluded. Data were extracted pertaining to the following variables: patient demographics; tumour localisation; clinical and imaging features; facial nerve function, hearing levels, and details of surgical intervention. Patient demographics are reported in Table I. In order to investigate the changes and eventual progresses of the surgical management during the 17-year period, 3 consecutive periods were explored separately: the earlier period (period 1) between 1990 and 1996, the intermediate period (period 2) between 1997 and 2001 and the last period group (period 3) between 2002 and 2006. Mean follow-up was  $5.9 \pm 2.4$  years.

All surgical procedures were performed by the same neuro-otological team (AR and MK, neurosurgeons; OS otologist) in a tertiary referral centre.

The FN function was assessed using the House-Brackmann (HB) grading system<sup>14</sup>. HB grade I or II, grade III or IV, and grade V or VI were defined as good, mild and poor FN function respectively. Intraoperative facial nerve monitoring (NIM and NIM II, Medtronic, Xomed, Jacksonville, FL, USA) was routinely used.

All patients completed a series of audiovestibular assessments including pure tone audiometry, intelligibility scores, auditory brainstem evoked responses and caloric and videonistagmography testing. Hearing level was evaluated using the American Academy of Otolaryngology-Head and Neck surgery (AAO-HNS) guidelines and staged in 4 classes<sup>15</sup>. Preservation of hearing was calculated as the sum of class A+B+C and a serviceable hearing as the sum of class A+B. Tumour size measurement was based on the largest extrameatal diameter in the cerebello-pontine angle (CPA) from T1-weighted MRI with gadolinium. The tumours were divided into 4 stages<sup>10-12</sup>: stage I (intracanalicular), stage II (inferior or equal to 15 mm in the CPA), stage 3 (from 16 to 30 mm in the CPA) and stage IV (superior to 30 mm in the CPA).

We analysed functional surgical outcomes among the three groups considering the following variables: completeness of tumour removal, intraoperative FN status, postoperative FN outcomes at one year, hearing preservation, CSF leakages and other complications.

### Statistical methods

Data are expressed as mean  $\pm$  SD. All data were analysed with the software SPSS 19.0. The  $\chi^2$  and Fisher's exact tests were used to compare surgical outcomes and the general characteristics of the three groups. Significance was considered at  $p < 0.05$ .

## Results

Preoperative clinical and radiological data are reported in Table I. No significant difference in demographics was observed among the patients in the three periods. Mean age was  $55.6 \pm 13.6$  years with a sex ratio of 0.88:1. VS was revealed by progressive or a sudden hearing loss in 84.3% or 10.7% of cases, respectively. Vertigo and tinnitus were present in 33.7% and 38.9% of cases, respectively.

Preoperative FN function was normal or subnormal in 98.8% cases. Trigeminal nerve dysfunction was observed in 17% of patients. Pre-operative useful hearing was in 41.7% and dead ear or absence of intelligibility in 35.5%. In the different groups, intracanalicular VS ranged from 7.7% to 9.%, stage 2 VS from 35.4% to 46.2% and large VS (stage 3 and 4) from 44.9 to 54.9%.

The surgical approach was chosen depending on: (i) tumour size, its extension into the CPA anterior to the inter-

**Table I.** Preoperative clinical and radiological data of patients.

Characteristic	Period 1 1990-1996 n = 268	Period 2 1997-2001 n = 299	Period 3 2002-2006, n = 439	Total 1990-2006 n = 1006
Male	105	151	216	472 (46.9%)
Female	163	148	223	534 (53.1%)
Left side	145	177	320	642 (63.8%)
Right side	123	122	119	364 (36.2%)
Age (yr)	64.2 ± 13.8	57.4 ± 12.4	55.3 ± 13.1	51.3 ± 13.6
Tumour size (mm)	19.0 ± 12.5	16.9 ± 10.8	16.4 ± 11.9	17.2 ± 11.7
<b>Tumour Stage</b>				
1	26 (9.7%)	23 (7.7%)	39 (8.9%)	88 (8.7%)
2	95 (35.4%)	136 (45.5%)	203 (46.2%)	434 (43.1%)
3	91 (34.0%)	97 (32.4%)	110 (25.1%)	298 (29.6%)
4	56 (20.9%)	43 (14.4%)	87 (19.8%)	186 (18.5%)
Trigeminal nerve dysfunction	55 (20.5%)	47 (15.7%)	69 (15.7%)	171 (17.0%)
<b>Facial nerve</b>				
HB I-II	266 (99.3%)	298 (99.7%)	430 (97.9%)	994 (98.8%)
HB III-IV	1 (0.4%)	1 (0.3%)	9 (2.1%)	11 (1.1%)
HB V-VI	1 (0.4%)	-	-	1 (0.1%)
Tinnitus	126 (47.0%)	133 (44.5%)	132 (30.1%)	391 (38.9%)
Vertigo	107 (39.9%)	128 (42.8%)	104 (23.7%)	339 (33.7%)
Otalgia	1 (0.4%)	1 (0.3%)	8 (1.8%)	10 (1.0%)
<b>Hearing loss</b>				
Progressive	223 (83.2%)	247 (82.6%)	378 (86.1%)	848 (84.3%)
Sudden	30 (11.2%)	32 (10.7%)	46 (10.5%)	108 (10.7%)
Class A	54 (20.1%)	68 (22.7%)	72 (16.4%)	194 (19.3%)
Class B	56 (20.9%)	84 (28.1%)	85 (19.4%)	225 (22.4%)
Class C	68 (25.4%)	70 (23.4%)	92 (21.0%)	230 (22.9%)
Class D	90 (33.6%)	77 (25.8%)	190 (43.3%)	357 (35.5%)
Headache	18 (6.7%)	16 (5.4%)	14 (3.2%)	48 (4.8%)
Intracranial hypertension	7 (2.6%)	1 (0.3%)	3 (0.7%)	11 (1.1%)

HB: House-Brackmann facial nerve grading system.

nal auditory meatus (IAM), at the IAM fundus, or intracochlear extension; (ii) ipsilateral and contralateral hearing level; (iii) general status and patients' expectations. Precisely, a translabyrinthine approach (TLa) for stage 3 and 4 VS or stage 1 and 2 VS with class C or D hearing loss; transotic approach (TOa) for stage 3 and 4 VS with extension anterior to the IAM or any stage VS with intracochlear extension; retrosigmoid approach (RSa) for stage 1 and 2 VS with class A or B hearing loss and IAM fundus free of tumour; and middle fossa approach (MFa) for stage 1 VS with class A or B hearing level. The extent of tumour resection was defined accordingly to the Acoustic Neuroma Consensus on System Reporting Results<sup>16</sup>.

Table II shows the approaches performed in relation to the size of VS. It appears that in few stages 2 MSa was chosen as well as RSa in few stages 3; TOa was mainly used in stage 4 VS. These approaches were differently used as a function of the period. More TLa and few RSa were performed during the early period as compared to the last one. More TOa and less MFa were performed during the last period.

#### *Intraoperative FN status and postoperative FN function*

Anatomical FN integrity was preserved in 983 patients (97.7%). Seven hundred and twenty-four patients (72.0%) completed the postoperative FN function evaluation at 1-year. There were 616 (85.1%), 103 (14.2%) and 5 (0.7%) patients with, respectively, good, medium and poor post-

**Table II.** Surgical approaches according to tumour stage.

	Tumour stage			
	1 (n = 88)	2 (n = 434)	3 (n = 298)	4 (n = 186)
TLa	27 (30.7%)	242 (55.8%)	259 (86.9%)	120 (64.5%)
TOa	10 (11.4%)	7 (1.6%)	17 (5.7%)	66 (35.5%)
RSa	1 (1.1%)	158 (36.4%)	22 (7.4%)	-
MFa	50 (56.8%)	27 (6.2%)	-	-

TLa: translabyrinthine approach; TOa: transotic approach; RSa: retrosigmoid approach; MFa: middle fossa approach.

**Table III.** Postoperative facial nerve function at 1 year.

	HB Grade I-II (%)	HB Grade III-IV (%)	HB Grade V-VI (%)
<b>Tumour stage</b>			
1 (n = 60)	55 (91.7)	5 (8.3)	-
2 (n = 333)	287 (86.2)	46 (13.8)	-
3 (n = 192)	163 (84.9)	27 (14.1)	2 (1.0)
4 (n = 139)	111 (79.9)	25 (18.0)	3 (2.2)
<b>Surgical approach</b>			
TLa (n = 456)	400 (87.7)	51 (11.2)	5 (1.1)
TOa (n = 61)	50 (82.0)	11 (18.0)	-
RSa (n = 143)	116 (81.1)	27 (18.9)	-
MFa (n = 64)	50 (78.1)	14 (21.9)	-
<b>Surgical period</b>			
Period 1 (1990-1996, n = 88)	69 (78.4)	18 (20.5)	1 (1.1)
Period 2 (1997-2001, n = 241)	201 (83.4)	38 (15.8)	2 (0.8)
Period 3 (2002-2006, n = 395)	346 (87.6)	47 (11.9)	2 (0.5)

HB: House-Brackmann facial nerve grading system; TLa: translabyrinthine approach; TOa: transotic approach; RSa: retrosigmoid approach; MFa: middle fossa approach.

operative FN function. The good FN function rate was inversely proportional to the tumour size (Table III): 91.7% in stage 1, 86.2% in stage 2, 84.9% in stage 3 and 79.9% in stage 4 (good FN function between stage 1 and 4 had significant difference,  $p = 0.04$ ). Good FN function was seen 87.7% of cases in TLa, 82.0% in TOa, 81.1% in RSa and 78.1% in MFa, and it was higher in TLa than that in MFa ( $p = 0.048$ ). Furthermore, the good FN function in period 1 was lower than that in period 3 (78.4% vs 87.6%,  $p = 0.02$ ). Out of 23 FNs interrupted during surgery, 13 (56.5%) were repaired by end-to-end anastomosis and 10 (43.5%) by great auricular nerve graft with fibrin glue<sup>17</sup>.

#### Hearing results

Out of 419 patients with a preoperative hearing level class A, B and C, 245 patients (58.5%) underwent tumour removal via RSa or MFa (Table IV). Overall, the hearing preservation rate was 61.6% (151 patients), and a serviceable hearing level was achieved in 82 patients (33.5%). Both these two rates in group 3 were higher than those in groups 1 and 2 (hearing preservation rate: 69.0% vs 50.9%,  $p = 0.028$ ; serviceable hearing preservation rate: 42.2% vs 21.8%,  $p = 0.01$ ).

#### Complications

The complications occurred in the present series are reported in Table V. CSF leakage occurred in 91 patients (9.0%), 72 of whom were treated conservatively with pressure dressings and lumbar drainage, and 19 underwent revision surgery. The management of CSF leakage was decided on the base of the cerebrospinal fluid pressure value<sup>18</sup>. According to the tumour size classification, the incidence of CSF leakage was 5.0% (4 cases) in stage 1, 7.4% (32 cases) in stage 2, 9.5% (28 cases) in stage 3 and 14.7% (27 cases) in stage 4. According to the surgical approaches, it occurred

**Table IV.** Hearing results at the last follow-up (n = 245).

Postoperative hearing level	Preoperative hearing level			
	A	B	C	Total (%)
A	30	7	-	37 (15.1)
B	16	27	2	45 (18.4)
C	17	30	22	69 (28.2)
D	50	30	14	94 (38.4)

in 7.9% (51 cases) in TLa, 12.2% (12 cases) in TOa, 10.5% (19 cases) in RSa and 11.7% (9 cases) in MFa.

We used four techniques of wound closure to prevent CSF leakage during the three consecutive periods<sup>19</sup>: 1) placement of the fascia graft on the dural defect and afterwards fat tissue placement over the fascia; 2) large musculoperiosteal flap to compress the fascia-fat complex; 3) fat tissue directly placed into the operative cavity without fascia graft, then covered with a musculoperiosteal flap; 4) fat tissue directly placed into the operative cavity and hold in place with a titanium plate fixed to the mastoid bone. The incidence of CSF leakage decreased along the three periods: 11.6%, 9.7% and 7.1% in the early, intermediate and last periods, respectively. Likewise, the incidence of postoperative septic meningitis decreased throughout the different periods: 1.9%, 1.3% and 0.7% in early, intermediate and last periods, respectively.

The mortality rate reported in this series was 0.3% (3 patients). One patient with stage 3 VS deceased of postoperative CPA hematoma. The two other patients presenting a stage 4 VS deceased of postoperative pulmonary embolism and cerebral haemorrhage, respectively.

Twelve patients (1.2%) with a total tumour resection presented a recurrence, detected through the routine annual MRI. The mean interval between surgery and recurrence was  $2.8 \pm 1.9$  years (range 1-6 years). The mean diameter of the

**Table V.** Postoperative complications (n = 1006).

Complications	Period 1 (1990-1996, n = 268) (%)	Period 2 (1997-2001, n = 299) (%)	Period 3 (2002-2006, n = 439) (%)	Total (1990-2006, n = 1006) (%)
Mortality	1 (0.4)	1 (0.3)	1 (0.2)	3 (0.3)
CPA haematoma	2 (0.7)	2 (0.7)	1 (0.2)	5 (0.5)
Subarachnoid haemorrhage	1 (0.4)	1 (0.3)	-	2 (0.2)
Lateral sinus thrombosis	1 (0.4)	1 (0.3)	1 (0.2)	3 (0.3)
Cerebellar oedema	-	1 (0.3)	1 (0.2)	2 (0.2)
Pulmonary embolism	1 (0.4)	-	1 (0.2)	2 (0.2)
Meningitis	5 (1.9)	4 (1.3)	3 (0.7)	12 (1.2)
Phlebitis	2 (0.7)	4 (1.3)	3 (0.7)	9 (0.9)
CSF leak	31 (11.6)	29 (9.7)	31 (7.1)	91 (9.0)
Revision	9 (3.4)	6 (2.0)	4 (0.9)	19 (1.9)
Conservative treatment	22 (8.2)	23 (7.7)	27 (6.2)	72 (7.2)
Lower cranial nerve palsy	-	1(0.3)	-	1 (0.1)
Subcutaneous abdominal haematoma	9 (3.4)	7 (2.3)	5 (1.1)	21 (2.1)
Recurrence	5 (1.9)	4 (1.3)	3 (0.7)	12 (1.2)

recurrence was  $10.4 \pm 3.6$  (range 5-15 mm). Among these 12 cases, five lesions were stable and continued to be observed, and 7 patients underwent surgical revision by TLa by reason of rapid growth tumour ( $> 2$  mm/year) or aggravating symptoms. There was no evidence of tumour regrowth in the 6 patients who underwent a near total tumour removal.

## Discussion

Over the last decades, the incidence of VS has increased to approximately 19 tumours per million per year. Several factors might be the cause of this increase, most important of which is the improvement in diagnostic equipment, i.e., magnetic resonance imaging, in a context of increased life expectation.

Along with the improvement of surgical techniques, the acquiring importance of radiosurgery and the advancement of diagnostic equipment led to a change in the objectives of VS treatment. Modern VS surgery is reaching the goal of preservation of function. Although facial nerve preservation was the major concern in the past decades, currently hearing preservation is the main challenge. To date, the choice of the surgical strategy depends on tumour size, hearing and facial nerve function, patient age and the presence of other disabling symptoms. The challenge and the matter of the actual debate is to achieve major tumour removal, with a minimal impairment of these functions.

The extension of tumour removal is strictly related to tumour size and to the adherence of the tumour to critical neurovascular structures<sup>5 20-22</sup>. The analysis of the present series shows that over the years advancements such as the electrophysiological monitoring of facial function influenced technical procedures and surgical outcomes. Overall in the present study, total tumour removal was reached in 99.4% of patients, with a higher rate of functional preservation in the last period. Moreover, the remaining 0.6% of patients who underwent a near total removal

was treated during period 3. In these cases (three stages 3 and four stages 4, mean tumour size:  $31.2 \pm 9.8$  mm), the presence of a tumour adherent to CPA structures led the surgeon to choose a conservative technique leaving in place a small residual. However, an average follow up of 5 years demonstrated the stability of the lesions and none of the cases presented a growth of the residual. Therefore, in line with other reports we can state that near total tumour resection might be a safe and effective method for preserving postoperative cranial nerve function without negatively impacting tumour control<sup>23</sup>.

### FN function

Several prognostic factors influence the postoperative FN function: tumour size, patient age, course of disease, previous treatment, surgical approach, intraoperative four-channel electromyography monitoring, FN displacement pattern, tumour adhesion and heterogeneous or cystic tumours<sup>4 10 24 25</sup>.

All surgeries were performed using a FN monitoring system. FN anatomical integrity does not necessarily correspond to good FN function. In our series, with 97.7% of FN anatomical integrity, good FN function was achieved only in 85.1% of patients. The good FN function rate varied from 91.7% to 79.9%, and it was inversely proportional to the tumour size. Thus, a larger tumour size implies a worse postoperative functional outcome. Recently, Esquia et al.<sup>10</sup> observed that the FN outcome is influenced by the displacement pattern and adhesion between the tumour and nerves. In addition, Bernat et al.<sup>25</sup> defined, as a criteria for good FN prognosis, the use of supramaximal stimulation threshold, that would increase the predictive value of monitoring during VS surgery.

Several authors have reported the results of FN preservation by various surgical approaches<sup>26-28</sup>. Our experience highlights that the choice of the approach has an influence

on functional outcomes. TLa and TOa (applicable to all tumour sizes) lead to an easier identification of the FN, on the other hand, in VS approached by MF the FN preservation rate was lower (78.1%). Finally, the surgeon's experience and postoperative rehabilitation training improved the results (87.6% in last period, 83.4% in intermediate period, and 78.4% in early period) without any change of the mean tumour size ( $p > 0.05$ ).

#### Hearing preservation

In the literature, data concerning hearing preservation vary from 18% to 96% of success<sup>1-4 6 26 29 30</sup>. In our series, RSa was used in tumour < 15 mm in CPA with class A or B hearing level and free fundus, while MFa was preferred in intracanalicular tumours with class A or B hearing level. Preserved hearing and serviceable hearing were obtained in 61.6% and 33.5% of patients, respectively. Both of these two rates in period 3 were significantly higher than in the earlier periods (hearing preservation rate: 69.0% vs. 50.9%,  $p = 0.028$ ; serviceable hearing preservation rate: 42.2% vs. 21.8%,  $p = 0.010$ ). As described, the preoperative pure tone average, free IAM fundus and tumour size<sup>32,33</sup> are predictive factors for hearing preservation, but we believe that surgical experience may be crucial for hearing preservation, and in particular for intraoperative identification and protection of blood vessels and cochlear nerve.

In the last decade (2007-2016), the strategy for hearing preservation in VS removal has seen some changes. More frequently than before, subtotal or partial removal of the tumour via RSa is proposed to patients, even with a class 3 VSs, followed by gamma knife radiotherapy.

#### Complications

Mortality rates associated with VS removal have been decreasing from 20 to 0% during the past decades, but still remain significantly higher in patients over 70 years<sup>33</sup>. Neurovascular disorders, brainstem injury and serious intracranial infections are the major causes of death. In our series, three patients deceased from CPA hematoma, pulmonary embolism and cerebral haemorrhage. All life-threatening complications occurred in patients with VS higher than stage 3.

CSF leakage was the most frequent perioperative complication in our series (9.0%). Our results confirm the relation between CSF leakage and tumour size (14.7% in stage 4, 9.5% in stage 3, 7.4% in stage 2 and 4.5% in stage 1)<sup>34,35</sup>, which is in contrast to what reported by Stieglitz et al<sup>36</sup>. However, its incidence is not related with the approach even if the occurrence of CSF leakage in TLa was lower (7.9%) than in the other approaches. Merkus et al.<sup>35</sup> reported 0.8% of CSF leakage after TLa during a 15-year period, suggesting some modification of closure techniques. Our incidence of CSF leakage decreased during the three periods (14.2% in early period > 9.0% in intermediate period > 5.9% in last period) demonstrating

that the development of closure technique and surgeon's experience helped to prevent this complication. Out of the four techniques of wound closure, the recent technique with a titanium plate anchored to the mastoid led to the most satisfactory results with a lower incidence of leakage compared to the average in the literature of 6.6% and 15%<sup>6</sup>. Consequently, the meningitis rate was 1.2%, which was lower than other reports (1.5%-2.6%)<sup>34 36-38</sup>.

The most serious complication in the present series was CPA hematoma. It usually occurs within the first 12 to 24 hours and the key point is the immediate removal and decompression of the CPA hematoma, even without confirmation by CT scan.

## Conclusions

Many factors influence the surgical outcomes of sporadic VS. Our experience in a large series of 1006 sporadic VS treated over a 17-year period revealed that good functional outcomes depend on several critical variables, including tumour size, surgical approach, surgeon's experience and development of technique.

Over the years the surgical outcome of sporadic VS has improved, in particular regarding facial nerve function outcomes and cerebrospinal fluid (CSF) leaks, mainly due to the neuro-otological team's experience. The actual challenge is hearing preservation after complete microsurgical removal of large VS, which depends on the experience gained on small VS removal.

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