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The otologic approach in the management of posterior petrous surface meningiomas

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Abstract

Purpose Report our experience in the management of posterior petrous surface meningiomas (PPSMs), and identify features that affect hearing, facial nerve (FN) function, and control of the disease.

Methods Retrospective case series of 131 patients surgically managed for PPSMs. FN status, hearing and tumour radicality were assessed and compared between patients with tumours of different locations (Desgeorges classification) and internal auditory canal involvement (IAC).

Results At the time of surgery 74.8% of patients had a hearing loss. Hearing was mostly unserviceable in tumors attached to the meatus. Pure tone audiometry did not correlate to IAC extension, while speech discrimination scores were statistically worse when the tumor occupied the IAC (unpaired *t* test, $p=0.0152$). Similarly, extrameatal tumors undergoing removal by otic preserving techniques maintained postoperative hearing, whereas hearing worsened significantly in tumors involving the IAC (paired *t* test, $p=0.048$). The FN was affected preoperatively in 11.4% of cases. Postoperative FN palsy was significantly correlated to the IAC involvement (Fisher's exact test, $p=0.0013$), while it was not correlated to tumor size. According to the Desgeorges classification, a postoperative FN palsy complicated the majority of anteriorly extending tumors and, two-fifths of meatus centred tumors. 75% of posterior located tumors had a postoperative FN grade I HB.

Conclusions Since the involvement of the IAC by the tumor affects both hearing and FN function, the IAC is of primary importance in PPSMs and should be studied and addressed as much as the tumor location in the CPA.

Keywords Meningioma · Cerebellopontine angle · Internal auditory canal · Facial nerve · Translabyrinthine · Petrous bone · Transapical

Introduction

Meningiomas are the most common primary intracranial tumor [1]. In 6–7% of cases, they arise from the posterior surface of the petrous pyramid [2]. Second only to Vestibular Schwannomas (VSs), meningiomas account for 3 to 12% of tumors of the cerebellopontine angle (CPA) and the internal auditory canal (IAC) [3, 4]. Hearing loss is the most frequent symptom, leading patients to seek otolaryngologic care [5].

An important feature of meningiomas is the invasion of bone, dura mater and inner ear structures [6–9]. Worse hearing after CPA meningioma removal is common [10–12].

In our center, hearing preserving techniques are generally reserved for tumors smaller than 2 cm with serviceable hearing [5]. However, hearing preserving techniques are increasingly being adopted by other surgeons, regardless of preoperative hearing [11]. Moreover, subtotal resection is performed, where permissible, to preserve hearing [12–14].

We report our experience in the management of posterior petrous surface meningiomas (PPSMs) and compare patients with different tumor dimensions, tumor localization and extension, histologies and surgical techniques adopted, to identify factors that influence facial nerve (FN) function, hearing and control of the disease.

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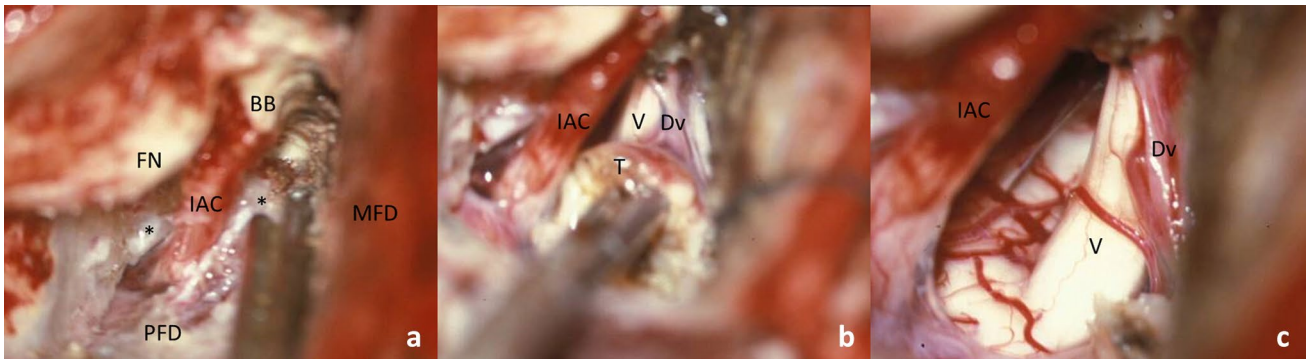

Fig. 1 Intraoperative photos of a left posterior petrous surface meningioma operated via a transalabyrinthine approach with transapical extension type II. **a** The internal auditory canal (IAC) has been decompressed as well as part of the posterior fossa dura (PFD). A superior and inferior through (*) is drilled towards the petrous apex. *FN* facial nerve, *BB* Bill's Bar, *MFD* middle fossa dura; **b** Type II extension: all the apical bone has been drilled with a 360° circumferential exposure of the IAC. The superior pole of the meningioma (T) is dissected from Dandy's vein (Dv) and trigeminal nerve (V); **c** Higher magnification with complete control of the prepontine cistern after tumor removal

Materials and methods

The study was approved by the institutional review board and all subjects gave informed consent for the use of their data. A retrospective analysis of all patients managed at our institution between December 1988 and July 2019 was performed. Of 4056 CPA tumors, 263 meningiomas were identified (6.5% of cases). Only surgically managed meningiomas with a posterior petrous surface origin were included. Patients with a tentorial, clival, petroclival, or jugular foramen origin, extending into the CPA, were excluded from the analysis. Twenty-two patients had pure intracanalicular meningiomas, they have been previously published and were excluded from this study [15]. Two patients were affected by neurofibromatosis type 2 and were also excluded. One hundred and thirty-one patients were finally included in this study.

All patients underwent preoperative hearing assessment by pure tone (from 125 Hz to 8 kHz) and speech audiometry. The pure-tone average (PTA) was calculated as the mean of the thresholds of 500 Hz, 1 kHz, 2 kHz, and 4 kHz. Hearing was classified according to the Tokyo consensus classification, based on PTA and speech discrimination scores (SDS) [16]: A when the PTA was 0–20 dB and the SDS 100–80%, B when PTA 21-30 dB and SDS 79–70%, C PTA 31–40 dB and SDS 69–60%, D PTA 41–60 dB and SDS 59–50%, E PTA 61–80 dB and SDS 49–40%, and F PTA > 80 dB and SDS 39–0%.

The preoperative and postoperative FN function was graded according to the House Brackmann scale [17]. All patients underwent gadolinium-enhanced magnetic resonance imaging (MRI). The Desgeorges classification system was adopted to subgroup the tumors according to their position with respect to the IAC in the CPA [18]: A anterior to the acoustic meatus; M centered on the meatus; P posterior to the IAC; AM both anterior and centered on the meatus; MP centered on meatus and posterior; AMP A, M and P combined. In parallel, tumors were divided according to the extent of IAC involvement (from porus to fundus): (i) pure extrameatal, (ii) porus involvement or up to less than half IAC, (iii) half IAC or more lateral extension, iv) up to fundus. Hearing and FN function were compared in the different groups.

Surgery was indicated according to age (radiologic follow-up is recommended in elderly patients with small tumors) and tumor dimensions. Tumors with an extrameatal diameter of two centimetres or more were given an immediate surgical indication. Preoperative hearing loss (class E or F) and disabling vertigo were indications for an otic disrupting (OD) approach. An extension anterior to the IAC or up to the fundus of the IAC was also an indication of an OD approach.

The OD approaches used were the translabyrinthine (TL) with or without a type II transapical extension, the transotic (TO), and the transcochlear (TC). The transapical extension was developed at our centre in the late nineties to ensure complete exposure of the posterior petrous surface (Fig. 1). It is an extension of the TL approach, in which a 360° circumferential drilling (type II) of the walls of the IAC is performed, conferring direct control and exposure of the anterior wall of the IAC, which is often infiltrated in meningiomas centred on the IAC or the petrous bone anterior to the IAC [19, 20]. The otic preserving approaches (OP) used were the retrolabyrinthine/retrosigmoid approach (RL/RS) for tumors with extrameatal extension, the middle cranial fossa (MCF) for tumors with only or mainly an intrameatal localization in patients up to 60 y.o., and the petro-occipital

transsigmoid (POTS) for tumors extending inferiorly into the jugular foramen. These approaches have been extensively described and refined over the years [21].

Two cases had been previously treated in other centres (one had undergone a partial retrosigmoid approach while one case had undergone stereotactic radiosurgery with tumor growth), their results were compared in relation to our treatment and were therefore not considered as residual or recurrent disease.

Intraoperative FN monitoring was conducted in all patients (AVALANCHE System, Dr. Langer Medical, Waldkirch, Germany), whereas intraoperative auditory evaluation with brainstem auditory evoked potentials was conducted when a hearing preserving approach was indicated (Nicolet Viking IV P System, Nicolet Biomedical, Madison, WI, USA). The extent of tumor resection was classified according to the Simpson scale [22]. All tumors were confirmed meningiomas on histopathologic analysis and were graded according to the World Health Organization classification of Central Nervous System Tumors (grade I: benign; grade II: atypical; grade III: anaplastic).

Postoperative complications and recurrences were recorded. Follow-up consisted of clinical and audiological evaluations, and annual MRI scans. Residual disease was treated with gamma-knife in case of growth at follow-up imaging.

FN status, hearing and tumor radicality were compared in different tumor dimensions, extensions (both in the CPA, as well as into the IAC), histologies, and surgical techniques.

Finally, the collected data were compared with data published in the literature.

Statistical analysis was performed using Graphpad Prism software (GraphPad Software, Inc, San Diego, CA, USA). The data collected from each patient were analysed using descriptive statistics; continuous variables were expressed as mean ± standard deviation; categorical variables were expressed as a percentage (frequency). Statistical analysis comparing PTA scores, SDS scores, or tumor diameters was performed using a paired or unpaired two-tailed Student's *t* test. The incidences of facial nerve status or the degree of tumor removal in different populations were studied using Fisher's exact test. ANOVA was used when there were more than two groups. Values were considered significant at $p < 0.05$.

Results

Demographic data

One hundred and thirty-one patients with PPSM were included in the study. There were no bilateral meningiomas. There was a predominance of female patients, 114/131 cases (87%). The mean age at the time of surgery was 53.6 years old (± 11.8). Follow-up had a mean of 46.7 months (± 38.8), median of 40 months (ranging from three months to 210 months).

Preoperative symptoms

At the time of surgery, 74.8% of patients presented hearing loss, 98 patients. Tinnitus affected almost half of the population, 62 patients. Fifty patients complained of instability, 38.2%, and 30 patients of vertigo, 22.9%. The FN was affected in 15 patients, 11.4%, and the trigeminal nerve in 21 patients, 16%. Almost 40% had serviceable hearing (classes A and B), whereas nearly one third had class F hearing (see Table 1).

Hearing did not vary according to tumor dimensions (one-way ANOVA, $p = 0.6048$). High frequencies were significantly more affected than lower frequencies ($p = 0.019$). Eight kHz was the most affected frequency.

Classification of the tumor

Patients were classified according to their dural attachment in respect to the auditory meatus (see Fig. 2) [16] as follows: 3.1% A (Fig. 2a), 13.0% M, 4.6% AM, 58.8% AMP (Fig. 2b), 12.2% MP, 8.4% P (Fig. 2c).

Preoperative progressive hearing loss affected all positions (Table 1). A class F hearing was presented in 41.2% of M classified tumors and 34.2% of AMP tumors. Tumors with a P attachment tended to have better hearing (45.5% class A).

IAC involvement

In parallel, patients were divided according to IAC involvement as evidenced by preoperative MRI and intraoperative findings (Table 2). The extrameatal diameter ranged from 2 mm to more than 70 mm (mean 24.7 mm ± 14). Although audiometric values in the affected ears tended to be worse in tumors that extended into the IAC (extrameatal or meatal attachment: 44 dB vs. IAC involvement: 59 dB), there was no statistically significant difference (unpaired t test, $p = 0.0585$). On the other hand, speech discrimination scores were significantly lower when the tumor extended into the IAC (unpaired t test, $p = 0.0152$, only extrameatal: SDS 82% vs. with IAC extension: SDS 60%).

Treatment

One case was a revision surgery after a retrosigmoid approach and one case had undergone stereotactic radiosurgery. All other cases, 129, underwent primary surgery. The majority of patients, 83 cases (63.4%), underwent a

Table 1 Number of patients classified according to their tumor dural attachment [18] and their preoperative symptoms and hearing

	Total	Class A	Class B	Class C	Class D	Class E	Class F	PHL	SSNHL	Tinnitus	Vertigo	Gait Insta-bility	Headache	Facial Palsy	Hemi-facial spasm	Trigeminal neuralgia	Facial numb-ness	Asymp-tomatic
A	4	0	1	1	1	0	1	4	0	2	0	2	0	1	0	0	1	0
AM	6	1	2	1	1	0	1	4	0	2	1	2	0	0	0	0	0	0
M	17	1	4	2	2	1	7	10	1	10	3	6	0	1	1	0	2	0
AMP	77	12	17	11	7	5	25	58	4	36	14	31	4	6	5	8	7	3
MP	16	2	7	0	1	3	3	11	0	8	6	4	0	1	0	1	2	1
P	11	5	3	0	1	0	2	5	1	4	6	5	0	0	0	0	0	1
All	131	21	34	15	13	9	39	92	6	62	30	50	4	9	6	9	12	5

A: petrous surface anterior to the internal auditory meatus; M: meatus; P: posterior petrous ridge; AM, AMP and MP are combinations. PHL: progressive hearing loss. SSNHL: sudden sensorineural hearing loss. Preoperative hearing is classified according to the Tokyo Consensus for reporting hearing results [16]

TL with a type II transapical extension, the approach was completed by a cul de sac closure of the external auditory canal in seven other cases. The second most frequently performed approach was the RL/RS, 20 cases (15.3%). A TO approach, a TC approach, a combined TL-RS, and a combined TL-transigmoid approach were performed in 4 (3.1%), 7 (5.3%), 5 (3.8%), and 2 (1.5%) cases, respectively. The MCF approach was used in only 2 cases (1.5%), whereas a POTS was performed in one case.

Patients with class E or F hearing underwent OD approaches. Half of the extrameatal tumors with class A and B hearing (11/21) were treated with an OP approach. On the other hand, patients with class A and B hearing and IAC involvement were treated through an OP technique in only 10/34 cases (29.4%). Two patients with class C and D hearing and no IAC involvement underwent an OP technique (2/7, 28.6%).

Histology

All cases were confirmed meningiomas on histological examination, with 51 cases of meningothelial meningiomas (38.9%), 52 transitional meningiomas (39.7%), 16 of fibroblastic type (12.2%), five psammomatous meningiomas (3.8%), four of angiomatous type (3.1%), two of mixed type (1.5%) and 1 anaplastic meningioma (0.8%). The latter was the only WHO grade III meningioma. We compared the FN function of each histologic diagnosis. Although not statistically significant, the FN appeared infiltrated in a higher percentage of fibroblastic meningiomas (Fisher's exact test, $p = 0.4221$).

Tumor removal/residual tumor

Gross total tumor removal (GTR) (Simpson grade I or II) was achieved in 81.9% of cases (107 cases, including the two cases that had undergone radiotherapy or partial removal through a RS approach elsewhere), whereas Simpson grade III and subtotal tumor removal (STR) or Simpson grade IV were achieved in 18.1% of cases (24 patients). Tumor diameter of patients undergoing GTR (mean 22 mm ± 13.5), was significantly smaller than those treated with an STR (mean 37 mm ± 10.3) (unpaired t test, $p < 0.0001$). There was no correlation with the use of an OP or OD approach (Fisher's exact test, $p = 0.5641$). Extrameatal tumors underwent a GTR in 84.2% of cases (32/38), while tumors with an intrameatal extension in 80.6% of cases (75/93) (Fisher's exact test, $p = 0.8045$). An AMP localization was the predominant extension undergoing an STR (21 out of 77 total AMP, 27.3%).

A STR was chosen in tumors surrounding the superior or anterior inferior cerebellar artery, extending into Meckel's cave and involving cranial nerves V and VI, tumors attached

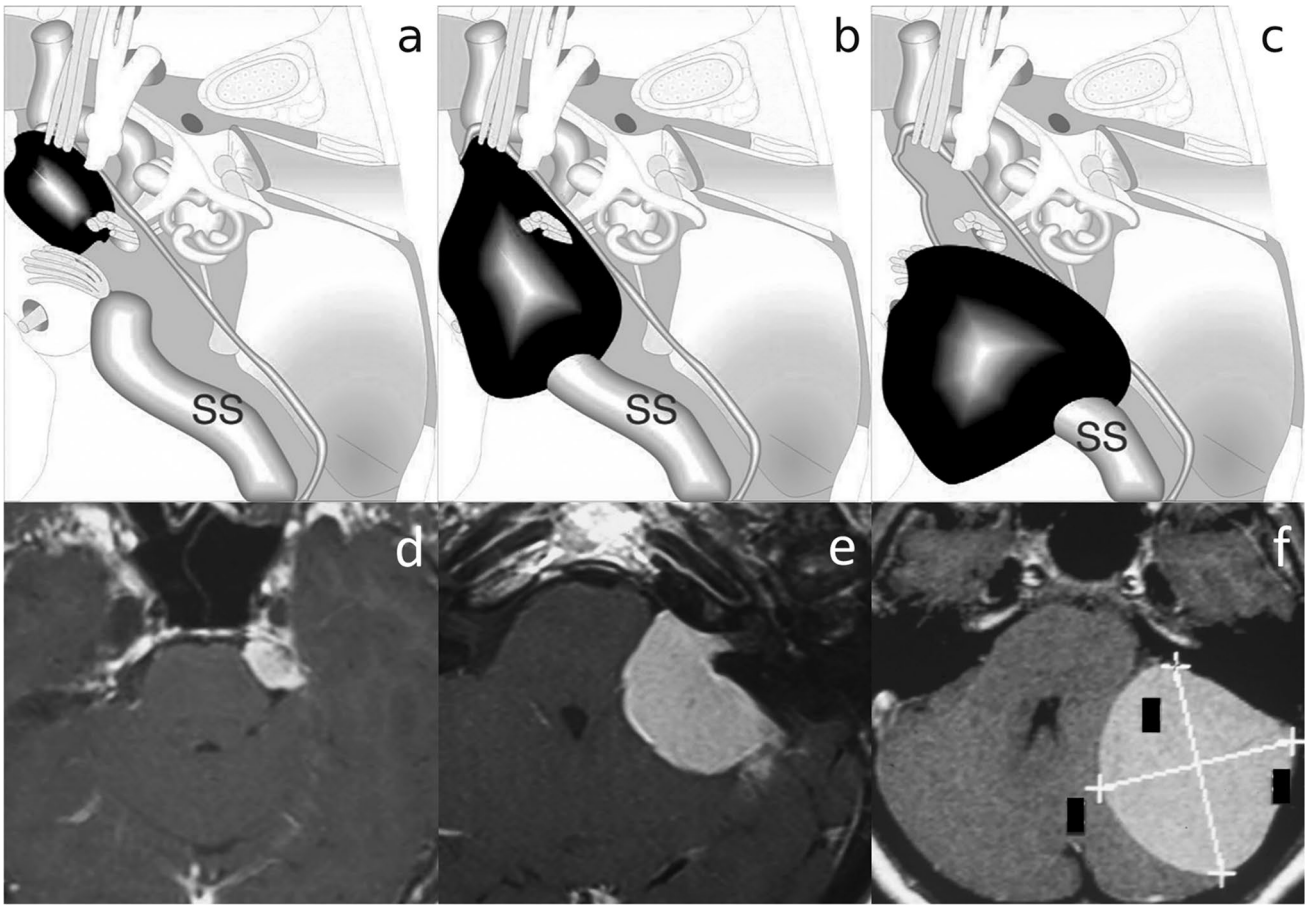

Fig. 2 Illustrations and MRI scans of meningiomas along the posterior petrous surface and their relationship with the cerebellopontine angle content. **a**, **d** anterior to the internal auditory meatus; **b**, **e** surrounding the meatus; **c**, **f** posterior to the internal auditory meatus. *SS* sigmoid sinus

Table 2 Internal auditory canal involvement

	EM dimensions (mm)	Hearing class (*N*)					Total (*N*)
		PTA (dB)	SDS (%)	A + B	C + D	E + F	
Only EM	29.1 ± 13	44 ± 32	82 ± 37	21	7	10	38
EM + IM	23.0 ± 14	59 ± 39	60 ± 45	34	21	38	93
Porus	28.2 ± 12	58 ± 37	60 ± 47	6	4	7	17
Middle	21.6 ± 14	58 ± 40	62 ± 45	28	15	29	72
Fundus	25.2 ± 18	81 ± 45	47 ± 55	0	2	2	4
All	24.7 ± 14	54 ± 38	67 ± 44	55	28	48	131

Dimensions, PTA and SDS are expressed as mean and SD. EM: extrameatal; IM: intrameatal; PTA: pure tone average; SDS: speech discrimination score; *N*: number of cases. Hearing is classified according to the Tokyo Consensus for reporting hearing results [14]. EM + IM: all porus, middle and fundus cases are grouped. Porus: tumors extending less than 50% into the internal auditory canal; middle: 50% or more of the internal auditory canal occupied; fundus: tumors reaching the fundus

to the lower cranial nerves or the hypoglossal canal. In two cases, residual tumor was left on the FN, postoperative FN function resulted in grade I in one case and grade VI in the other.

Twenty-two percent of twenty-four patients with residual tumor were treated with a postoperative gamma knife (five patients) due to tumor growth on imaging (ranging from one to nine years after surgery). One of the latter shrank, while the rest presented stable dimensions on subsequent radiological follow-up (range of follow-up: five to fourteen years). The rest of STR cases underwent follow-up with annual MRI.

Recurrence

There were two (1.9%) recurrent meningiomas, after 51 and 96 months, which are kept under radiological follow-up. The first had undergone a TL approach for an AMP located meningioma with IAC extension, whereas the second was after a RL/RS approach for a P meningioma. During follow-up, a second primary meningioma developed in one patient.

Facial nerve results

At the last follow-up, 3.8% of patients presented a FN function grade VI (five patients), 1.5% grade V (two patients) and 11.5% grade IV (15 patients) (see Table 5 for grade I, II and III). Extrameatal meningiomas presented a grade I HB in 23 cases (60.5%) and a grade IV-VI HB in 4 cases out of 38 (10.5%), whereas cases with an IAC involvement presented a grade I HB in 27 cases (29%) and a grade IV-VI HB in 18 cases out of 93 (19.3%) (Fisher's exact test, $p=0.0013$). One patient developed a delayed facial palsy which eventually recovered completely.

The FN was infiltrated by tumor and therefore sacrificed in 11.5% of cases (15 cases). One-third of these cases presented preoperative facial palsy. Thirteen sacrificed FNs were immediately reconstructed by sural nerve interposition grafting [23], resulting in seven grade III HB, two grade IV HB, one grade V HB and two grade VI HB. In two cases a graft was not necessary and the two stumps were stabilized with fibrin glue, they resulted in a grade III HB and a grade IV HB. Two patients (one had previously undergone sural nerve interposition grafting) underwent a hypoglossal-facial anastomosis [24], resulting in one grade III HB and one grade IV HB.

In 3.8% of cases (5 cases), the patients presented preoperative facial palsy or hemifacial spasm, but no intraoperative evidence of facial infiltration, the nerve was, therefore, preserved. Postoperatively, only one of these patients had a normal FN function. On the other hand, two patients presented intraoperative FN infiltration and residual tumor was left on the nerve to preserve its function. Only one maintained postoperative FN function.

FN outcome did not correlate to tumor dimensions. On the other hand, FN infiltration was significantly correlated with IAC involvement (Fisher's exact test, $p=0.0292$).

According to the Desgeorges' classification, type P tumors were the least affected by postoperative facial palsy (75% grade I HB). Among M tumors, 58.8% of patients presented normal FN function at the last follow-up, with 10% of patients having gone FN sacrifice and 31.2% presenting an FN palsy despite an intact nerve. Anterior tumor extension was associated with worse facial function results, with most patients presenting at the last follow-up a grade III (39/87 patients) or IV (12/87 patients).

At the last follow-up, 38.6% of patients who underwent a TL approach, with or without a TA extension, maintained FN function grade I or II, and 90% of patients who were operated with an RL/RS approach.

Hearing results

Table 3 shows the postoperative hearing results of patients who underwent an OP approach: two class M underwent an MCF, one class AMP underwent a POTS, the rest underwent a RL/RS. In extrameatal tumors, where an OP technique was adopted, preoperative and postoperative PTA results did not vary significantly (preoperative PTA preoperative PTA 23.3 dB vs postoperative 32.6 dB; paired t test, $p=0.061$). On the other hand, postoperative PTA was significantly worse when the tumor extended into the IAC (preoperative PTA 22.5 dB vs postoperative 38.1 dB; paired t test, $p=0.048$). Posteriorly located tumors were most likely to preserve hearing, whereas an anterior extension was mostly associated with a postoperative dead ear (see Table 3).

Complications

One patient had a perioperative complication with an immediate postoperative ventriculoperitoneal shunt positioned for increased intracranial pressure.

Postoperatively, eight (6.1%) patients presented lower cranial nerve palsy (six AMP and two MP). Canial nerve VI was compromised in nine patients (6.9%) (all AMP). Finally, only one patient continued to complain trigeminal neuralgia and four patients (3.1%) complained of hemifacial anaesthesia, three of whom developed new symptoms (all AMP).

Five patients (3.8%) developed subcutaneous cerebrospinal fluid (CSF) leak, four had IAC involvement. Two had undergone a RL/RS approach (10%), while the other three had undergone a TL and TO approach (two, 2.2%, and

Table 3 Postoperative hearing of patients classified according to their tumor dural attachment [18] undergoing otic preserving approaches

Tumor dural attachment	OP approach/ total cases	Preserved	Decreased	Improved	Dead ear
A	0/4	–	–	–	–
AM	1/6	0	0	0	1
M	6/17	3	3	0	0
AMP	9/77	2	3	1	3
MP	2/16	1	1	0	0
P	5/11	4	1	0	0

OP: otic preserving; A: petrous surface anterior to the internal auditory meatus; M: meatus; P: posterior petrous ridge; AM, AMP and MP are combinations

one, 25%, respectively). The latter three underwent surgical revision.

Discussion

Anteriorly located PPSMs may appear with a trigeminal involvement, although facial numbness and trigeminal neuralgia are more usual in larger tumors occupying an AMP position. Posteriorly located tumors appear with vertigo and gait instability. Meatus-centred PPSMs typically suffer from hearing loss, vertigo and tinnitus and occasional facial palsy or hemifacial spasm. In general, hearing loss represents the most common symptom of patients with PPSMs. Although other authors describe the hearing loss in 52–59% of patients [10, 12], our series had compromised hearing in almost 75% of cases. This higher prevalence, which was also evidenced in tinnitus and vertigo, could be a selection bias because cases with otologic symptoms are mostly referred to an otologist. However, it could also result from more thorough otologic examinations. Highest frequencies, although not considered in hearing classifications, are the most affected frequencies. Similarly to this series, 8 kHz is the predominantly affected frequency in VSs [25].

Two-thirds of the tumors in our series extended into the IAC, almost double the incidence of other published series, where IAC invasion is present in merely one third to 40% of cases [12, 26]. Involvement of the IAC was associated with worse preoperative hearing, which could also explain the higher incidence in our series.

Considering the effect on hearing, and given that other authors have noted an increased risk of residual disease in the IAC [27], when more than half of the IAC is involved we prefer to adopt approaches that offer more control, even if they disrupt the otic capsule. We favour hearing preserving techniques only when hearing is serviceable. According to Nakamura et al., intrameatal tumors preserve preoperative cochlear nerve function in 22.7% of cases [7]. More than half of the patients of this series had postoperative hearing deterioration. Four patients had a postoperative dead ear, and eight patients had worsening of their hearing. When the IAC is involved there is a tendency towards worsening.

Anteriorly located meningiomas and meatus-centered meningiomas were associated with substantially low postoperative serviceable hearing [28]. Table 4 shows the hearing results of the series in which a classification of hearing is used. Some authors imply excellent postoperative hearing results, but since their results are not presented we cannot analyse them [10, 29].

According to the literature review, one-third of the population with a normal or serviceable hearing before surgery will eventually lose hearing after an OP approach. Hearing loss may occur due to the inability to preserve the cochlear nerve. Moreover, hearing loss may occur despite the anatomical integrity of the cochlear nerve, due to stretching and compression of the fibres, reduction in its vascularisation or occlusion of the labyrinthine artery.

The FN is notoriously more affected in meningiomas than VSs, due to their more aggressive nature [13, 30]. One-third of fifteen cases requiring FN sacrifice presented preoperative symptoms. On the other hand, only one case of five patients with preoperative facial symptoms but no evidence of FN infiltration presented postoperative normal FN function. Even if not infiltrated, again stretching and compression of the nerve cause damage. The damage is probably accentuated by the adherent nature of meningiomas, the need for more aggressive intraoperative manoeuvres and the resulting surgical trauma [15]. The rate of anatomical preservation of the FN is always higher than the functional preservation [14].

Table 4 Hearing classification of cases undergoing otic preserving approaches in literature, according to Gardner and Robertson scale or the American Academy Committee on Hearing and Equilibrium guidelines

Study	OP approach	I or A *n* (%)		II or B *n* (%)		III/V or C/D *n* (%)		Classification
		Pre	Post	Pre	Post	Pre	Post	
Schaller B et al. 1999 [34]	31	13 (41.9)	11 (36.7)	6 (19.4)	5 (16.7)	12 (38.7)	14 (46.7)	G&R
Bassiouni et al. 2004 [41]	51	13 (29.5)	11 (25.0)	14 (31.8)	11 (25.0)	17 (38.6)	22 (50.0)	G&R
Shen et al. 2004 [42]	37 (data on 29 pts)	22 (75.9)	20 (71.4)	0 (0)	2 (7.1)	7 (24.1)	6 (21.4)	AA
Nakamura et al. 2005 [11]	347 (data on 333 pts)	201 (60.4)	133 (42.4)	54 (16.2)	33 (10.5)	78 (23.4)	148 (47.1)	HAC
Deveze et al. 2007 [43]	20/43	11 (55.0)	7 (35.0)	8 (40.0)	4 (20.0)	1 (5.0)	9 (45.0)	AA
Peyre et al. 2011 [29]	22/53	22 (100)	17 (77.3)	0 (0)	0 (0)	0 (0)	5 (22.7)	AA
Nowak et al. 2013 [33]	45/48	22 (50.0)	21 (47.7)	14 (31.8)	7 (15.9)	8 (18.2)	16 (36.4)	G&R
Present study	23/131	21 (91.3)	13 (56.5)	2 (8.7)	5 (21.7)	0 (0)	5 (21.7)	G&R,AA

Pre: preoperative; Post: postoperative; OP: otic preserving; n: number; AA: AAO-HNS; G&R: Gardner-Robertson; HAC: Hannover Audiological Classification: different scale, cases were reclassified according to speech discrimination score, where class H1/H2 was reclassified as A, H3 as class B, and H4/H5 as class C/D

Meningiomas vary in consistency from soft to firm/fibrous, influencing the ease of resection and the risk of surgical morbidity [31]. In our series, fibroblastic meningiomas had a higher percentage of FN infiltration, but no statistically significant differences emerged.

Larger tumors are associated with a higher incidence of facial palsy [12], although this association was not confirmed in this series. On the other hand, IAC involvement correlated significantly with postoperative facial palsy in this series (facial palsy in 66/93 patients in IAC involvement vs. 15/38, $p = 0.0013$) and FN infiltration (Fisher's exact test, $p = 0.0292$). Other authors state that opening the IAC is not associated with worse facial outcomes [12], however, the radicality in the IAC is not specified. It is uncertain whether leaving residual tumor in the IAC might be better for hearing and FN preservation and whether opening the IAC might also decompress the nerve. Only in two cases tumor was left on the FN with the intention of preserving it anatomically, but the functional outcomes varied (grade I and VI HB). Anyhow, tumor removal and detachment from the nerves are certainly more traumatic [15].

Table 5 collects the functional outcomes of the FN from various articles in which the results are discussed according to the HB classification. Surprisingly, only our series has a considerable number of postoperative grade III FN function. We can assume that the higher incidence of IAC tumor extension is a possible explanation. Moreover, most of our cases are localized AMP which are associated with 37% of facial palsy [28]. The interobserver variability of the HB grading system could also influence the reliability of our or other authors' grading [33].

VSs, apart from exceptional cases, displace the cochlear and FN anteriorly [21, 32]. This arrangement facilitates the surgeon, who unveils the tumor before exposing the two nerves. Contrarily, PPSMs can arise from any position around the IAC (Fig. 1). Similarly to VSs, retromeatal meningiomas often maintain both hearing and FN function [33, 34]. In anteriorly attached tumors, the facial and cochlear nerves are displaced posteriorly, between the tumor and the surgeon [11]. This explains why anteriorly located tumors are associated with worse postoperative FN function and difficulty in preserving hearing.

Meningiomas are highly vascularized and may surround and adhere to vessels. In a larger series, postoperative haemorrhage occurred in 3.5% of patients, requiring surgical evacuation in three-quarters of them, and leading to the death of one of the patients [11]. GTR is particularly difficult in PPSMs compared to other locations due to the difficult anatomy and the presence of vital structures [35]. On the other hand, recurrences are rare once a GTR has been achieved (see Table 6). Moreover, involvement of the IAC reduces GTR when this is not specifically addressed and treated [36]. The extensive use of the TL approach may explain why there was no difference in tumour radicality between extrameatal meningiomas and tumours extending into the IAC in this study. Drilling of the invaded bone and IAC are essential steps to increase GTR, although other authors report a slight increase in CSF leak, especially when associated with the RS approach [12, 37].

In agreement with the literature STR or Simpson grade IV was done in 18.1% of cases to preserve vital structures. Larger tumors were significantly associated with an increased incidence of STR.

Although our numbers are very limited to assume any conclusion, similarly to other authors, we indicate radiosurgery only in small and growing residual tumors [10, 38]. Other authors recommend postoperative radiosurgery on the residual tumor rather than following the patient [39]. Since

Table 5 Facial nerve function literature review, according to the House-Brackmann scale

Study	I—*n* (%)		II—*n* (%)		III—*n* (%)		IV–VI—*n* (%)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Schaller B et al. 1999 [34]	21 (67.7)	14 (45.2)	1 (3.2)	4 (12.9)	1[a] (3.2)	3 (12.9)	8[b] (25.8)	10[b] (32.3)
Bassiouni et al. 2004 [41]	53 (93.0)	50 (87.7)	4 (7.0)	2 (3.5)	0 (0)	1 (1.8)	0 (0)	4 (7.0)
Shen et al. 2004 [42]	63 (95.5)	46 (78.0)	1 (1.5)	0 (0)	1 (1.5)	3 (5.1)	1 (1.5)	10 (16.9)
Nakamura et al. 2005 [11]	284 (85.0)	297 (91.7)	30 (9.0)	Grade I and II together	8 (2.4)	26 (8.0)	12 (3.6)	6? (0.3)
Wu et al. 2005 [14]	71 (86.6)	65 (79.3)	4 (4.9)	1 (1.2)	7 (8.5)	6 (7.3)	0 (0)	10 (12.2)
Deveze et al. 2007 [43]	37 (86.0)	27 (62.8)	2 (4.7)	2 (4.7)	2 (4.7)	10 (23.3)	2 (4.7)	4 (9.3)
Peyre et al. 2011 [29]	44 (83.0)	36 (69.2)	6 (11.3)	4 (7.7)	2 (3.8)	4 (7.7)	1 (1.9)	8 (15.4)
Nowak et al. 2013 [33]	44 (91.7)	37 (77.1)	3 (6.3)	1 (2.1)	0 (0)	5 (10.4)	1 (2.1)	5 (10.4)
Present study	124 (94.7)	50 (38.2)	1 (0.8)	10 (7.6)	3 (2.3)	49 (37.4)	3 (2.3)	22 (16.8)

Pre: preoperative; post: postoperative; n: number

[a]grade III and IV

[b]only grades V and VI

Table 6 Literature review of subtotal tumor resection, recurrences and cerebrospinal fluid leak complication in posterior petrous surface meningiomas undergoing surgical removal

Study	*N*	CSF leak *n* (%)	STR *n* (%)	Recurrence *n* (%)
Schaller B et al. 1999 [34]	31	0 (0%)	4 (13%)	–
Bassiouni et al. 2004 [41]	51	5 (9.8%)	8 (15.7%)	2 (3.9%)
Shen et al. 2004 [42]	46[a]	4 (6%)	3 (6%)	–
Nakamura et al. 2005 [11]	334	16 (4.6%)	47 (14.1%)	–
Wu et al. 2005 [14]	82	8 (9.8%)	14 (17.1%)	5 (6.1%)
Deveze et al. 2007 [43]	43	5 (11.6%)	9 (20.9%)	0 (0%)
Baroncini et al. 2011 [10]	89[a]	11 (16%)	38 (42.7%)	–
Peyre et al. 2011 [29]	53	–	15 (28%)	–
Roche et al. 2011 [29]	57	3 (5.3%)	35 (61%)	–
Nowak et al. 2013 [33]	48	–	3 (6.25%)	2 (4.2%)
D'Amico et al. 2017 [38]	51[a]	4 (7.8%)	7 (13.7%)	5 (9.8%)
Lynch et al. 2018 [44]	28	4 (14.2%)	6 (21.5%)	2 (7.1%)
Magill et al. 2018 [13]	51	3 (6%)	19 (37.3%)	8 (15.7%)
Peraio et al. 2018 [12]	63[a]	3 (5%)	21 (33%)	–
Bu et al. 2020 [45]	162[a]	–	0 (0%)	13 (8%)
Present study	131	5 (3.8%)	24 (18.1%)	2 (1.5%)

N number, *CSF* cerebrospinal fluid

[a]only posterior petrous bone meningiomas undergoing surgery were considered

only 22% of our patients with residual tumor were eventually treated with radiosurgery because of tumor growth, we do not agree with this strategy. According to other authors, FN function remains unchanged in all patients receiving radiosurgery as initial therapy [38]. However, salvage surgery is associated with 73.3% of facial palsy in VSs [40]. Since meningiomas are generally associated with worse facial outcomes [15], we do not suggest radiosurgery as an attempt to preserve facial function. Radiosurgery alone can be indicated in small growing tumors in elderly patients or patients with poor general conditions contraindicating surgery. We may indicate radiosurgery also in patients with tumor in the only hearing ear, especially when a hearing preserving technique is not indicated, although a thorough wait and scan should precede radiotherapy when possible.

Conclusion

To conclude, PPSMs are aggressive CPA tumors due to their nature and location but have a low risk of being malignant (one anaplastic meningioma among 131 PPSMs). Hearing is often impaired leading patients to seek an otolaryngologist, which may explain the high incidence of hearing loss in this series. Tumor within the IAC affects preoperative hearing (significantly worse speech discrimination scores, $p = 0.0152$), increases the risk of FN infiltration ($p = 0.0292$) and increases postoperative neurologic deficit (hearing loss, $p = 0.048$, and FN palsy, $p = 0.0013$). Leaving residual tumor in the IAC to preserve hearing is uncertain which is why we prioritize total tumor removal over attempting to preserve hearing. If hearing were to deteriorate with time due to the presence of the tumor, the effort would be counterproductive. Similarly debatable is the effect of residual tumor on the FN and whether it will guarantee normal postoperative FN function.

We believe that the Desgeorges' classification, although sufficient for some meningiomas, lacks the description of the IAC. Since the effects on hearing and FN function vary depending on the extent of IAC involvement (from medial to lateral), this addition, would not only explain the worse hearing in some meningioma cases but also justify OD approaches that offer complete removal of the IAC walls and therefore decrease the probability of regrowth of the tumor.

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Declarations

Conflict of interest There is no conflict of interest involved.

Ethical statement This article does not contain any studies with human participants or animals performed by any of the authors. The study was approved by our Institutional Review Board. Additional informed consent was obtained from all individual participants for whom identifying information is included in this article. However, the article does not contain any direct information regarding patient identity.

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