Early-Career Surgical Practice for Cerebellopontine Angle Tumors in the Era of Radiosurgery

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Abstract

We analyzed the outcomes of patients with large cerebellopontine angle (CPA) tumors treated by a skull-base team in which two surgeons (one neurosurgeon and one otological surgeon) were in the beginning of their careers (<40 years old). Data of patients operated on between April 2012 and March 2016 were reviewed. All factors related to surgical training were considered. Thirty-one patients had vestibular schwannomas, while 26 had meningiomas. Mean tumor diameter was 30.6 mm (range, 23–49 mm) for schwannomas and 35 mm (range, 22–51 mm) for meningiomas. Satisfactory postoperative facial nerve function (House–Brackmann's grade I or II) was achieved in 20 (64.5%) schwannoma patients and 21 (80.7%) meningioma patients. Gross total and near-total resections (residual tumor < 5 mm) were achieved in 21 (67.7%) and 9 (29%) schwannoma patients, respectively. Gross total resection (Simpson's grade II) was achieved in 18 (69.2%) meningioma patients. In both groups, the retrosigmoid approach was the most common approach. Regarding surgical training of the two younger surgeons, during the residency period, they attended high-volume centers for CPA tumors. Application of microsurgical techniques was systematically applied from the beginning of their personal series in every intracranial pathology case. During the first 2 years of the series, they were supervised by more experienced surgeons and followed a stepwise sharing of increasingly difficult surgical phases; by comparing results of this period with the last 2 years of the series, where they acquired a complete autonomy, no relevant difference was detected. Our results suggest that young surgeons may achieve good results even at the beginning of their careers, if specific conditions related to training and mentorship are met.

Keywords

- cerebellopontine angle tumor
- retrosigmoid
- skull base
- translabyrinthine
- vestibular schwannoma

Introduction

Cerebellopontine angle (CPA) tumors are challenging to resect because of their complex regional anatomy, the deep and narrow surgical corridors involved, and the abundance of vital neurovascular structures in the surgical field. Consequently,

neurosurgeons approaching these tumors should carefully take into account how to reduce any adverse impact on patients' quality of life.^{1,2} Nowadays, thanks to the availability of web-based information sharing and peer group blogs, patients have access to data from highly specialized neurosurgical centers which have accumulated large series over

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decades.^{3,4} Furthermore, the past two decades have witnessed the rise of radiosurgery as a powerful alternative to surgery, especially for schwannomas and meningiomas smaller than 2.5 cm.^{5–7} As well, radiological follow-up of small tumors has been demonstrated to be an acceptable strategy.⁸ These developments have decreased the number of CPA tumors treated using conventional surgery worldwide, and most importantly, have led to neurosurgeons managing predominantly large CPA tumors, which require a more robust surgical experience than small tumors. This situation represents a great burden for young skull-base surgeons, for whom the learning curve in CPA tumors has become very steep.⁹

The aim of this article is to retrospectively analyze the management strategy for and surgical results of a series of consecutive patients with large schwannomas and meningiomas in the CPA that were treated by a team of surgeons who were in their early careers and progressively gained competency and eventually complete autonomy in this type of surgery.

Materials and Methods

We retrospectively reviewed all clinical and surgical files, outpatient clinic registries, and pre- and postoperative neuroimaging data of patients with CPA tumors that were operated on between April 2012 and March 2016. Demographics, preoperative Karnofsky performance status (KPS), symptoms at onset, and preoperative tumor diameter were recorded in all patients. In patients with vestibular schwannomas, we also considered the Hannover's classification (►Table 1) and measured the maximum diameter of the cisternal component of the tumor. Meningiomas were classified based on the position of the dural implant into meatal, premeatal, postmeatal, and petroclival meningiomas (►Fig. 1), and their maximum diameter was measured. We also analyzed the surgical records to confirm the position of the dural implant and its relationship with nerves. In all the study patients, we noted the type of skull-base approach and the surgical position as well as the reasons why the surgeons chose them. Facial nerve function was assessed using the House–Brackmann's (HB) grading system.¹⁰ A postoperative HB grade I or II was considered satisfactory; grades III indicated mild facial nerve dysfunction, while grades IV to VI indicated severe dysfunction. We also noted the results of the pre- and postoperative evaluations of the vestibulocochlear nerve and other cranial nerves.

Table 1 Hannover's classification

Grade	
T1	Purely intracanalicular
T2	Intrameatal or extrameatal
T3a	Filling the cerebellopontine cistern
T3b	Reaching the brain stem
T4a	Compression of the brain stem
T4b	Compression of the brain stem with dislocation of the fourth ventricle

Fig. 1 Three-dimensional rendering of the cerebellopontine angle demonstrating the relationship of meningiomas' position with the internal auditory canal (This image is provided courtesy of UpSurgeOn.com.)

The primary outcome indices were definitive postoperative KPS scores (at least 6 months after the operation), definitive hearing and facial nerve functions (at 9 months at least), and extent of resection (EOR) as observed on postoperative magnetic resonance imaging (MRI). In the case of vestibular schwannomas, the EOR was classified as total (absence of any contrast enhancement on postoperative MRI), near-total (residual tumor, <5 mm), or subtotal (residual tumor, >5 mm). For meningiomas, the Simpson' grading of tumor resection was used. Postoperative MRI was evaluated by expert neuroradiologist from our institution. Secondary indices were duration of surgery, blood loss, and need for transfusion. Intra- and postoperative surgical complications and mortality were also assessed.

We further separated surgical results according to two distinct periods of time: the first 2 years of the series, where the two young surgeons were systematically joined by more experienced surgeons and the last two where they gained a complete surgical autonomy. Statistical analysis was performed to determine whether there was a statistically significant difference between the two phases of their early careers. We used binary logistic regression with duration (minute) and maximum diameter (mm) as continuous covariate and experience as categorical covariate to predict three outcomes: EOR (total vs. subtotal), neurological deficit (yes vs. no, or HB >2 vs. HB <2), and definitive KPS (>90 vs. <90). We also used a two sample *t*-test to compare the two different samples (2012 vs. 2014) for the continuous covariates.

Concerning the surgical training of the two younger surgeons, we reviewed their residency program and their specific surgical career to ascertain which factors influenced more the learning curve in CPA tumors surgery.

Results

In total, 57 patients underwent surgery for CPA tumors during the study period. Of these, 31 patients had vestibular schwannomas, while 26 harbored meningiomas. Intraoperative facial

nerve monitoring was performed in all patients; in addition, 5th and 9th to 11th nerves monitoring (Nicolet Viking, Natus Europe GmbH, Planegg, Germany) were performed depending on tumor position and extension. In patients whose tumors caused severe brain stem compression, transcranial somatosensory evoked potentials were monitored as well. The patients' clinical and radiological data are summarized in ► **Table 2**.

Vestibular Schwannoma

The average age of the 31 patients with vestibular schwannomas was 55 years (range, 25–76 years). The mean maximum diameter of these tumors was 31.6 mm (range, 23–47 mm). Of

note, 27 tumors (87%) belonged to grades 3b, 4a, and 4b of the Hannover's classification. The most frequent symptoms at onset were unilateral hypoacusia and tinnitus (90.3%, 28 patients), dizziness (54.8%, 17 patients), facial hypoesthesia (35.4%, 12 patients), and gait disturbance (29%, 9 patients). One patient presented with symptoms related to hydrocephalus, and an external ventricular drain was inserted before the opening. Preoperative KPS scores were ≥ 90 in 90.3% (28 patients); the principal cause of low KPS scores was the presence of gait disturbance. At definitive follow-up, only one patient experienced a slight decrease in his neurological status. All patients underwent a vestibulocochlear evaluation; cochlear nerve preservation was attempted only in patients

Table 2 Demographic, radiological, and functional pre- and postoperative data

	Vestibular schwannoma (n = 31)	Meningioma (n = 26)
Age, mean (range)	55 y (25–76 y)	60 y (34–77 y)
Preop KPS > 90	28 (90.3%)	18 (69.2%)
Definitive postop KPS > 90	27 (87%)	19 (73%)
Symptoms at primary onset	Hypoacusia, tinnitus, vertigo, fifth nerve dysfunction, gait disturbance	Gait disturbance, seventh and fifth nerves dysfunction, difficulty swallowing
Maximum preop tumor diameter, mean (range)	31.6 mm (23–49 mm)	37 mm (22–51 mm)
Tumors measuring <25 mm in diameter	3 (9.6%)	2 (7.6%)
Schwannoma grade/ meningioma location	Hannover's classification	Position
	Grade 4B, 12 patients	Premeatal, 11 patients
	Grade 4A, 6 patients	Postmeatal, 5 patients
	Grade 3B, 9 patients	Meatal, 6 patients
	Grade 3A, 3 patients	Petroclival, 4 patients
	Grade 2, 1 patient	
Definitive seventh nerve function		
HB grade 1 or 2	20 (64.5%)	21 (80.7%)
HB grade 3	8 (25.8%)	1 (3.8%)
HB grades 4–6	3 (9.6%)	2 (7.6%)
Definitive hearing status		
Anacusia	28 (88.8%)	1 (3.8%)
Hypoacusia	3 (11.1%)	5 (20.3%)
Extent of resection		
Total	21 (67.7%)	18 (69.2%); Simpson's grade II
Near total	9 (29%); residual tumor < 5 mm	5 (19.2%)
Subtotal	1 (3.2%); residual tumor > 5 mm	3 (11.5%); Simpson's grade III
CSF fistula	5 (16.1%)	4 (15.3%)
Cerebellar infarction	1 (3.2%)	1 (3.8%)
Mortality	0	1 (4%)
Number of relapses (only patients with at least 1 y of MRI follow-up)	2 (6.4%)	1 (3.8%)

Abbreviations: CSF, cerebrospinal fistula; HB, House-Brackmann; KPS, Karnofsky performance scale; MRI, magnetic resonance imaging; preop, preoperative; postop, postoperative.

Fig. 2 A 38-year-old woman. (A) A grade 4b schwannoma is showed on T1 postcontrast axial MRI. The patient was obese with very short neck. Hearing was unserviceable. We chose a right RSA in semisitting position to maximize the intracranial pressure reduction. (B) Postoperative MRI showing near-total resection (red circle) and wide opening of the internal auditory canal (red arrow). HB 4 recovered completely after 6 months. MRI, magnetic resonance imaging; RSA, retrosigmoid approach.

with small tumors (<25 mm, 3 patients), and those with pure tone average < 60 dB and speech discrimination > 50% (3 patients) on audiometry. Postoperatively, 28 (88.8%) patients had nonserviceable hearing, while 3 had good tonal audiometry but scarce speech discrimination. The definitive facial nerve status was good in 64.5% of patients (HB grades I and II). Gross total resection was achieved in 21 patients (67.7%), while near-total resection was achieved in 9 patients (29%) (► **Fig. 2**).

Meningioma

The mean age of the 26 patients with meningiomas was 60 years (range, 34–77 years). There were 11 premeatal, 5 postmeatal, 6 meatal, and 4 petroclival meningiomas. The mean tumor diameter was 37 mm (range, 22–51 mm). Only two patients had a tumor diameter < 25 mm. Symptoms at the time of onset consisted of gait disturbance (46.1%), hearing loss and tinnitus (38.4%), facial numbness (23%), and difficulty in swallowing (7.6%). Eighteen patients (69.2%) had a preoperative KPS score $\geq$ 90, while at the definitive evaluation, KPS scores of $\geq$ 90 were present in 73% (19 patients). Satisfactory facial nerve function (HB grade I or II) were achieved in 88% of patients, while postoperative hypoacusia was present in 20.3% patients. Four patients experienced a transient difficulty in swallowing, but this completely resolved at 2 and 6 months postoperatively. A Simpson's grade II resection was achieved in 69.2% patients (► **Fig. 3**). In five patients, the postoperative MRI showed a contrast-enhanced region of $\leq$ 5 mm at the dural attachment or in neurovascular structures.

Intraoperative Findings

Among vestibular schwannoma patients, the retrosigmoid approach was most commonly used (21 out of 31 patients, 67.7%). The translabyrinthine approach (► **Fig. 4**) was selected in case of the following: tumor completely filling the internal auditory canal, elderly patient (to reduce cerebellar manipulation), and patient with a history of partial resection via the retrosigmoid approach (at another institution). All translabyrinthine operations (10 patients, 32.2%) were performed with the patients in a supine position, whereas for retrosigmoid operations, the park-bench position (16 patients, 51.6%) or

Fig. 3 A 54-year-old man with debilitating ataxia, left facial numbness, and hypoacusia. (A–D) Preoperative T1 axial postcontrast MRI showing a large meningioma of the left CPA with attachment on the petrosal apex as well as tentorium. A left retrosigmoid craniotomy was performed with the patient in semisitting position. (E–H) Postoperative MRI showing total resection of the tumor. Patient complaints a mild left facial numbness and, occasionally, diplopia in the downward gaze. CPA, cerebellopontine angle; MRI, magnetic resonance imaging.

Fig. 4 A 71-year-old man with gait disturbances and right deafness. (A, B) Preoperative T1 axial postcontrast MRI showing a partly cystic large schwannoma (4b) of the left CPA. Due to age and the penetration of the tumor deep into the internal auditory canal (red arrow), we chose a TLA. (C, D) Postoperative MRI and CT showing complete resection. Postoperative facial paresis HB 5 recovered to HB 2 after 8 months. CPA, cerebellopontine angle; CT, computed tomography; MRI, magnetic resonance imaging; TLA, translabyrinthine approach.

sitting position (5 patients, 16.1%) was used. The sitting position was selected instead of the park-bench position in patients with very large tumors (>35 mm to minimize bleeding which may hinder microdissection) or tumors that extended up to or beyond the midline or involved the incisura tentorii (►Fig. 5). In five patients (16.1%), cerebrospinal fluid (CSF) leakage or inadequate wound healing was reported. In three of these patients, a second surgery was needed. The mortality was 0.

Among the meningioma patients, the retrosigmoid approach was selected in 23 patients (88.4%). In two of these patients, the tumor extended to the lower clivus, and so, the retrosigmoid approach was combined with a far lateral approach with partial drilling of the condyle (►Fig. 6). Of these 23 patients, 12 (52.1%) were operated on in a semisitting position for the same reasons as noted earlier. In one patient, the translabyrinthine approach was used because he had already undergone surgery via the retrosigmoid approach. In two more patients, a combined petrosal approach was used. These two patients were operated on during the early period of the series; lateral extended approaches were later abandoned. Postoperative CSF fistulas developed in 15.3% patients, and resolved in all of these patients after external lumbar drainage. One patient died (4%) on post-

Fig. 5 A 74-year-old man with gait disturbances and right deafness. (A) Preoperative T1 axial postcontrast MRI showing a large schwannoma (4b) of the right CPA. Due to the excellent cisternal space and optimal clinical condition of the patient, we performed a right retrosigmoid craniotomy with the patient in park-bench position. (B) Postoperative MRI showing subtotal resection (>5 mm) with little residue at the level of the cisternal segment of the FN. The patient experienced a facial paresis HB 4 that completely regressed 7 months later. At 30 months, the residue is stable. CPA, cerebellopontine angle; FN, facial nerve; MRI, magnetic resonance imaging.

operative day 20 due to myocardial infarction (an autopsy demonstrated no other causes of death).

In the entire patient cohort, the sitting position was converted to the park-bench position in 3 of 22 patients (13.6%) because of air embolism; there were no fatal consequences. All detailed data are reported in ►Tables 3 and 4.

Specific Considerations for the Learning Process

By analyzing the residency period and the beginning of their surgical career as junior consultants, both surgeons focused on CPA tumor surgeries and spent at least 2 years in departments with high-volume skull-base tumor cases (meaning at least 40 cases of CPA tumor per year) where anatomy laboratories and dedicated multidisciplinary boards were available. In those centers, they performed as assistant surgeons more than 45 cases of CPA tumors and they started to approach the tumors through the arachnoid dissection. On the contrary, during their residency period, they participated in approximately 30 CPA surgeries; in this period, the main focus was on the positioning of the patient and the learning of the surgical approaches. Microsurgery was the core of their surgical training with systematic application during every single case of intracranial (G.S.) or otological surgery (T.S.). This translated in the application of microsurgical instruments and techniques even during resection of tumors of other cranial districts or more superficially located.

Analyzing the operative reports, it appeared that during the first 2 years of this series, G.S. and T.S. were systematically joined by more experienced surgeons. During this period, G.S. performed all the positioning, opening, arachnoid dissection, and tumor debulking for all the patients operated on through the retrosigmoid approach (not only schwannomas and meningiomas), and also performed arachnoid dissection and tumor debulking for the remaining tumors operated on through the translabyrinthine approach.

Fig. 6 A 39-year-old woman with progressing swallowing difficulties and headache. (A–C) Preoperative T1 axial postcontrast MRI showing a large petroclival meningioma. A left retrosigmoid craniotomy was performed with the patient in semisitting position. (D–F) Postoperative MRI showing subtotal resection of the tumor with residue at the level of the anterior foramen magnum. Patients complained immediate postoperative swallowing difficulties and diplopia (left sixth nerve). At the 45 days from surgery, the patient was totally asymptomatic and fully active. At 16 months, the residue is stable. MRI, magnetic resonance imaging.

T.S. performed positioning and opening for translabyrinthine operations under supervision during the opening of the internal auditory canal. Intuitively, the passage from the supervised period to the complete autonomy phase passed through intermediate steps where young surgeons were responsible for the procedure but with always a more experienced surgeon available for help or support.

If we compare the characteristics of the patients according to the two periods of the series, there are no significant differences in preoperative tumors' dimensions and Hannover's grade (for vestibular schwannomas) and dimension and position (for meningiomas) neither for EOR. As well, there were no evident differences considering intraoperative parameters such as blood loss and need for transfusions. A slight decrease in operative times was noted for both groups. Other outcome measures such as definitive KPS or postoperative facial nerve status were also similar (► **Tables 3** and **4**). The diameters were comparable between the two samples; time instead was inferior in the second sample. Looking at the statistical analysis, experience was never significant in all the models. The most important factor was time that could, at least in part, be linked to experience. However, we think that the longer operative time during the supervised part of the series could be directly related to specific need for support by younger surgeons (► **Tables 5–7**).

Discussion

CPA tumors are very challenging lesions to treat, even in the hands of expert neurosurgeons. An advanced anatomical knowledge, mastery of microsurgical techniques, three-dimensional mental imagery, and the ability to correlate intraoperative and radiological imaging are indispensable for the successful resection of CPA tumors. Young neurosurgeons interested in posterior skull-base surgery can experience difficulties in building their surgical practice during the early period of their careers because of a very steep learning curve.⁹ The concept of learning curve has been analyzed and discussed in various surgical fields, including laparoscopic procedures,¹¹ esophageal surgery,¹² and head and neck surgery.¹³ The learning curve not only helps in documenting sequential skill acquisition but it can also be used to quantify the case load required to achieve expert proficiency, with subsequent implications for the design of surgical training programs.¹⁴ However, it is not as straightforward as setting a minimum number of procedures above which a neurosurgeon has expert competency. Some authors have tried to verify this concept for vestibular schwannoma surgery and estimated a range from as low as 20 to as high as 100 procedures.^{9,14} Ideally, surgical skills should be improved sequentially through the management of increasingly

Table 3 All the meningioma patients' pre-, intra-, and postoperative characteristics are summarized

Period 2012– 2014	Age	Onset	Tumor's diameters	Position	Surgery year	Approach	Position	Surgery duration (min)	Blood loss (mL)	Trans- fusion	Extent of resection	KPS post- operative	Postoperative neurological status	Hearing status	Complications	Hospital discharge	Definitive facial status	Definitive KPS	Relapse (minimum 1 y MRI follow-up)
1	57	Incidental	22 × 19 × 20	Premetal	2012	RS	PB	290	75	No	Total	90	Normal	Normal	No	7 home	1	100	No
2	74	Facial pain	30 × 27 × 22	Premetal	2012	RS	PB	380	140	No	Total	80	Facial hypoesthesia, diplopia (fourth nerve)	Normal	No	13 home	1	90	No
3	73	Gait ataxia, headache, facial weakness (HB 2), anacusia, dysmetria	40 × 25 × 23	Meatal	2012	TL	SUP	580	230	No	Near total	80	Ataxia, vertigo	Anacusia	No	26 home	4	100	No
4	66	Gait ataxia, hydrocephalus, hypoacusia, urinary incontinence	43 × 33 × 39	Premetal	2012	RS	SP	540	250	No	Total	70	Right hyposthenia, gait imbalance	Hypoacusia	No	20 rehab	1	80	No
5	58	Gait disturbance, headache, dizziness	42 × 30 × 35	Petroclival	2012	RS	SP	520	300	No	Total	80	Diplopia, ataxia, hypoacusia, facial weakness	Normal	No	19 rehab	1	90	No
6	44	Diplopia, dysphagia, left tongue atrophy, and deviation	38 × 37 × 30	Petroclival	2013	RS	PB	530	120	No	Total	60	Lower cranial nerve dysfunction (temporary gastrostomy)	Normal	Pneumonia	18 rehab	1	80	No
7	70	Headache	30 × 27 × 22	Premetal	2013	RS	PB	290	130	No	Total	90	Normal	Normal	No	19 home	1	100	No
8	77	Gait ataxia	41 × 32 × 35	Meatal	2013	RS	PB	520	160	No	Near total	70	Normal	Normal	No	25 home	1	90	No
9	74	Facial pain, facial hypoesthesia	31 × 27 × 22	Premetal	2013	Combined	SUP	550	310	No	Subtotal	80	Normal	Normal	No	12 home	1	100	No
10	59	Severe gait ataxia	36 × 30 × 24	Premetal	2014	RS	SP	540	420	No	Near total	60	Hemiparesis, severe ataxia, dysphagia	Hypoacusia	No	26 rehab	2	70	No
11	67	Gait ataxia, headache	51 × 44 × 41	Postmeatal	2014	RS	PB	260	90	No	Subtotal	80	Normal	Normal	No	18 home	1	90	No
12	61	Headache, gait ataxia, incontinence	41 × 33 × 31	Postmeatal	2014	RS	PB	320	130	No	Total	70	Gait ataxia	Normal	No	12 home	1	100	No
13	49	Facial weakness (HB 2), facial hypoesthesia, ataxia	43 × 37 × 30	Petroclival	2014	Combined	SUP	810	580	Yes	Subtotal	80	Gait ataxia, facial hypoesthesia, HB 5	Hypoacusia	No	21 home	4	100	Yes, Gamma knife
			Mean tumor diameter: 38 mm					Mean: 471.5	Mean: 225.7			Mean 76.1					Mean: 1.5	Mean: 91.5	
Period 2014–2016																			
14	52	Gait ataxia, left hemihypoesthesia, and weakness	42 × 39 × 35	Meatal	2014	RS	SP	410	290	No	Total	80	Left hemisindrome, gait ataxia	Normal	No	12 rehab	2	90	No
15	34	Headache, swallowing disturbances	41 × 32 × 35	Petroclival	2014	RS	SP	490	190	No	Near total	90	Slight tongue deviation, swallowing disturbances, diplopia (sixth nerve)	Normal	No	13 home	1	100	Yes, initial increase of the residue but stable
16	65	Gait ataxia, headache	51 × 47 × 40	Postmeatal	2015	RS	PB	280	110	No	Total	90	Normal	Normal	No	18 home	1	100	No

(Continued)

Table 3 (Continued)

Period 2012– 2014	Age	Onset	Tumor's diameters	Position	Surgery year	Approach	Position	Surgery duration	Blood loss (mL)	Trans- fusion	Extent of resection	KPS post- operative	Postoperative neurological status	Hearing status	Complications	Hospital discharge	Definitive facial status	Definitive KPS	Relapse (minimum 1 y MRI follow-up)
17	56	Facial weakness (HB 2), dysphagia, gait ataxia	36 × 34 × 24	Premotal	2015	RS	SP	430	210	No	Total	80	Slight dysphagia, hemihypoesthesia	Normal	no	In-hospital death (day 20)			No
18	39	Hemifacial hypoesthesia, dizziness	35 × 23 × 34	Premotal	2015	RS	SP	510	330	No	Total	100	Diplopia (fourth cranial nerve)	Normal	No	11 home	1	100	No
19	52	Facial hypoesthesia, gait ataxia, hypoacusia	51 × 40 × 44	Premotal	2015	RS	SP	450	200	No	Total	90	Slight diplopia (fourth cranial nerve)	Hypoacusia	no	10 home	1	100	No
20	46	Hypoacusia, tinnitus	26 × 20 × 19	Medial	2015	RS	SP	390	130	No	Total	80	Facial weakness	Normal	No	18 home	1	90	No
21	52	Headache, gait ataxia	40 × 28 × 26	Postmeatal	2015	RS	SP	260	90	No	Total	90	Normal	Normal	No	9 home	1	100	nr
22	47	Facial hypoesthesia, facial weakness (HB 2)	4 × 2 × 2.5	Premotal	2016	RS	SP	390	190	No	Total	90	Hypoacusia, HB III, ataxia	Hypoacusia	No	12 rehab	3	100	nr
23	71	Headache, gait disturbance, dizziness	35 × 32 × 29	Medial	2016	RS	PB	270	100	No	Total	90	Ataxia, slight diplopia	Normal	No	14 rehab	1	90	nr
24	64	Headache	45 × 37 × 32	Postmeatal	2016	RS	PB	280	90	No	Total	90	Normal	Normal	No	10 home	1	100	nr
25	68	Gait ataxia, left hemihypoesthesia, and weakness	41 × 30 × 26	Premotal	2016	RS	SP	550	350	Yes	Near total	70	Left hemisindrome	Normal	No	20 rehab	1	80	nr
26	59	Incidental	23 × 18 × 21	Postmeatal	2016	RS	PB	165	80	No	Total	100	Normal	Normal	No	8 home	1	100	
			Mean tumor diameter: 38 mm					Mean: 375	Mean: 181.5			Mean: 87.6					Mean:1.25	95.8	

Abbreviations: HB, House-Brackmann; KPS, Karnofsky performance status; PB, park bench; RS, retrosigmoid; TL, translabyrinthine; SP, sitting position; SUP, supine.

Note: Series has been separated according to two time periods.

Table 4 All the schwannoma patients' pre-, intra-, and postoperative characteristics are summarized

Period 2012– 2014	Age	Onset	Tumor's diameters	Hannover's grade	Year of surgery	Approach	Position	Surgery time	Blood loss (mL)	Trans- fusion	Extent of resection	Postop KPS	Postop facial status (HB)	Hearing status	Complica- tions	Hospital discharge	Definitive facial status HB	Definitive KPS	Relapse (minimum 1 y MRI follow-up)
1	36	Hypocacusia	25 × 22 × 20	3b	2012	RS	PB	300	80	No	Total	100	4	Anacusia	No	9 home	2	100	No
2	63	Hypocacusia, facial numbness	26 × 18 × 20	4a	2012	RS	PB	500	200	No	Total	100	2	Anacusia	No	15 home	1	100	No
3	65	Dizziness, hypocacusia	33 × 32 × 25	4b	2012	RS	PB	505	120	No	Near total	90	3	Anacusia	No	12 home	1	90	No
4	74	Gait ataxia, hypocacusia, dizziness, facial numbness	35 × 34 × 2.4	4b	2012	RS	PB	500	220	No	Total	80	3	Anacusia	No	20 home	2	90	No
5	25	Hypocacusia	31 × 28 × 27	3a	2012	TL	SUP	490	110	No	Total	100	3	Anacusia	No	10 home	2	100	No
6	64	Tinnitus, hypocacusia, dizziness	30 × 27 × 22	3b	2012	RS	PB	380	200	No	Total	90	4	Anacusia	No	12 home	2	100	No
7	62	Tinnitus, hypocacusia	27 × 21 × 18	3b	2012	RS	PB	540	230	No	Total	80	5	Anacusia	No	15 home	3	100	No
8	51	Tinnitus, hypocacusia, facial numbness	31 × 27 × 22	3a	2013	RS	PB	410	340	No	Near total	90	3	Anacusia	CSF leak	18 home	2	100	Yes, Gamma Knife
9	74	Hypocacusia, dizziness	35 × 33 × 27	3b	2013	RS	PB	440	250	No	Total	80	4	Anacusia	No	13 home	2	100	No
10	38	Facial numbness, hypocacusia, gait ataxia, dizziness	40 × 32 × 35	4b	2013	TL	PB	620	800	Yes	Near total	90	5	Anacusia	No	12 home	4	90	No
11	66	Gait ataxia, hypocacusia, facial numbness, dizziness	33 × 32 × 27	4a	2013	RS	PB	630	220	No	Total	80	5	Anacusia	No	18 rehab	3	90	No
12	64	Tinnitus, dizziness	23 × 21 × 18	3b	2013	TL	SUP	330	75	No	Total	100	4	Hypocacusia	No	9 home	2	100	No
13	36	Hypocacusia, tinnitus, dizziness	35 × 33 × 27	4b	2013	TL	SUP	600	220	No	Total	90	5	Anacusia	No	11 home	3	100	No
14	48	Hypocacusia, gait ataxia, facial numbness	41 × 40 × 37	4b	2013	RS	PB	420	130	No	Near total	100	3	Anacusia	No	9 home	1	100	No
15		Hypocacusia, facial numbness	31 × 31 × 27	4a	2014	RS	PB	660	170	Yes	Total	80	4	Anacusia	CSF leak (surgical correction)	13 home	3	80	No
16	65	Gait ataxia, dysphagia, hypocacu- sia, dizziness, facial numbness	45 × 39 × 33	4b	2014	RS	PB	580	420	No	Near total	80	5	Anacusia	No	21 Rehab	5	90	No
			Mean: 32.5					Mean: 496.1	Mean: 236.5			Mean: 89.3	Mean: 4			Mean: 13.5	Mean: 2.3	Mean: 95.3	
Period 2014–2016																			
17	32	Headache, gait ataxia, hypocacusia, dizziness	34 × 34 × 32	4b	2014	RS	SP	350	100	No	Near total	80	5	Anacusia	Infection	18 rehab	3	80	Yes, Gamma Knife
18	46	Hypocacusia, tinnitus, facial numbness, gait ataxia	40 × 35 × 30	4b	2014	RS	PB	515	210	No	Subtotal	90	5	Anacusia	Infection	15 home	2	100	No
19	62	Hypocacusia, dizziness	25 × 22 × 20	3b	2014	RS	SP	282	310	No	Total	100	2	Anacusia	No	13 home	1	100	No
20	33	Dizziness	23 × 19 × 20	3b	2015	RS	PB	240	50	No	Total	100	2	Hypocacusia	Infection	17 home	2	100	No
21	70	Tinnitus, dizziness	23 × 16 × 18	3a	2015	TL	SUP	380	40	No	Total	100	5	Hypocacusia	CSF leak (surgical correction)	16 home	3	100	No
22	55	Hypocacusia, tinnitus	26 × 20 × 19	4a	2015	RS	SP	355	110	No	Total	100	4	Anacusia	No	8 home	1	100	No
23	57	Hypocacusia, tinnitus	26 × 25 × 21	4a	2015	TL	SUP	405	300	No	Total	90	4	Anacusia	No	13 home	2	100	No
24	69	Hypocacusia, headache, gait ataxia, dizziness, facial numbness (hydrocephalus)	41 × 33 × 36	4b	2015	RS	SP	480	300	No	Near total	80	4	Anacusia	Infection, CSF leak	22 home	3	80	No
25	51	Hypocacusia, tinnitus	30 × 27 × 22	4b	2015	TL	SUP	590	470	No	Total	100	4	Anacusia	CSF leak	30 home	4	100	No
26	67	Hypocacusia, dizziness	27 × 26 × 22	4a	2016	RS	PB	270	100	No	Total	90	2	Anacusia	No	9 home	1	100	nr

(Continued)

Table 4 (Continued)

Period 2012– 2014	Age	Onset	Tumor's diameters	Hannover's grade	Year of surgery	Approach	Position	Surgery time	Blood loss (mL)	Trans- fusion	Extent of resection	Postop KPS	Postop facial status (HB)	Hearing status	Compli- cations	Hospital discharge	Definitive facial status HB	Definitive KPS	Relapse (minimum 1 y MRI follow-up)
27	50	Hypoaacusia, tinnitus, dizziness, facial numbness	38 × 37 × 36	4b	2016	RS	SP	465	680	No	Near total	90	4	Anacusia	No	10 home	3	100	nr
28		Hypoaacusia, dizziness	26 × 21 × 19	4a	2016	TL	SUP	270	50	No	Total	90	5	Anacusia	No	8 home	2	100	nr
29	70	Hypoaacusia	28 × 25 × 27	4a	2016	TL	SUP	335	145	No	Total	70	4	Anacusia	No	19 home	2	80	nr
30	63	Hypoaacusia, facial numbness	27 × 25 × 21	4b	2016	RS	SUP	280	150	No	Total	90	4	Anacusia	No	10 home	2	100	nr
31	52	Hypoaacusia, tinnitus, gait ataxia, dizziness, facial numbness	49 × 4 × 3.5	4b	2016	TL	SUP	530	285	No	Near total	90	5	Anacusia	No	9 home	2	100	nr
			Mean: 31					Mean: 383.1	Mean: 220			Mean: 90.6	Mean: 3.8			Mean: 14.4	Mean: 2.2	Mean: 96	

Abbreviations: CSF, cerebrospinal fluid; HB, House–Brackmann; KPS, Karnofsky performance status.
Note: Series has been separated according to two time periods.

complex cases (in terms of volume and location). Following the rise of radiosurgery as the treatment of choice for small-to-medium skull-base tumors, neurosurgeons tend to operate predominantly on large tumors. This situation has deepened the gap between “senior” neurosurgeons (who have had the opportunity to resect tumors of all volumes) and “junior” neurosurgeons. Apart from intrinsic tumor factors such as hypervascularity, tumor consistency, and tumor-to-nerve adhesion, functional and oncological outcomes for both meningiomas and schwannomas are undoubtedly related to tumor volume and location.^{15–17} Moreover, as demonstrated by authors who focused on the treatment of large and giant CPA tumors, a negative correlation exists between the EOR and postoperative functional outcome.^{18–20} Due to the availability of effective radiosurgical treatments and with the goal of offering a better quality of life, a shift in the treatment paradigm has been observed toward a more judicious resection in case of an objectively high risk of neural damage.^{21,22} Corroborating this assumption, recent studies have supported the notion that residual tumors may lay dormant for many years.^{23,24} However, at the practical level, achieving a near-total resection in large CPA tumors is more difficult than it is generally believed since stopping resection at the right moment requires experience and judgment. In our institution, we follow the principle of attempting total resection under the constant surveillance of neurophysiological monitoring which means halting resection when alterations in facial nerve responses suggest potential severe damage. Looking at current experience and comparing to updated literature review, there seems to be a good agreement of results with modern large series^{25–33} for both functional outcomes and resection strategies (–Table 8). These data are more relevant if one considers the fact that most of our patients were operated on by skull-base surgeons who were at the beginning of their careers. However, the current rate of postoperative CSF leak and wound infection is high; we hypothesize that a better evaluation of preoperative CSF disturbances with a consequent more aggressive intraoperative management (positioning of external ventricular drainage) could lead us to reduce this complications.

Undoubtedly, mentorship seems to have a crucial role in the creation of a personal surgical experience. Mentorship translates into the staged sharing of increasingly difficult surgical steps. Even when younger surgeons acquire the necessary skills to completely manage difficult cases, more expert surgeons are always available for support and advise. In other word, we would represent this process like a gradient rather than a 0/1 event. However, we arbitrarily separated the time frame of the current series in two periods and we did not find substantial differences in outcomes, witnessing a progressive acquisition of competency.

Globally speaking, it is clear that the acquisition of competency and skills should encompass at least two fields of interest: on the one hand, there are aspects related to the global management of patients with CPA tumors. Trainees interested in this type of surgery should attend high-volume centers for CPA tumor cases and learn the entire

Table 5 Statistical analysis for meningioma

Meningiomas						
	B	E.S.	Wald	df	Sig.	Exp(B)
EOR						
Experience	−1.113	1.139	0.955	1	0.328	0.328
Diameter	−0.093	0.095	0.965	1	0.326	0.911
Time	−0.011	0.006	3.810	1	0.051	0.989
Constant	10.173	5.268	3.729	1	0.053	26,188.486
KPS						
Experience	−0.565	1.395	0.164	1	0.686	0.568
Diameter	−0.010	0.102	0.010	1	0.920	0.990
Time	−0.006	0.005	1.652	1	0.199	0.994
Constant	5.372	4.282	1.574	1	0.210	215.340
Neurological outcome						
Experience	1.806	1.294	1.949	1	0.163	6.089
Diameter	0.025	0.072	0.117	1	0.732	1.025
Time	−0.014	0.005	6.776	1	0.009	0.986
Constant	3.163	2.944	1.155	1	0.283	23.651

Abbreviations: EOR, extent of resection; KPS, Karnofsky performance status.

Note: Binary logistic regression with duration (minute) and maximum diameter (mm) as continuous covariate and experience as categorical covariate to predict three outcomes: EOR (total vs. subtotal), definitive KPS (>90 vs. <90), and neurological deficit (yes vs. no).

Table 6 Statistical analysis for schwannoma patients

Schwannomas						
	B	E.S.	Wald	df	Sig.	Exp(B)
EOR						
Exp(1)	0.111	2.067	0.003	1	0.957	1.117
Diameter	−0.673	0.267	6.331	1	0.012	0.510
Time	0.012	0.012	1.018	1	0.313	1.012
Constant	17.415	6.515	7.144	1	0.008	36,561,748.600
KPS						
Exp(1)	1.854	1.438	1.664	1	0.197	6.388
Diameter	−0.010	0.093	0.012	1	0.914	0.990
Time	−0.004	0.007	0.455	1	0.500	0.996
Constant	3.494	2.712	1.659	1	0.198	32.907
HB > 2						
Exp(1)	2.579	1.497	2.966	1	0.085	13.181
Diameter	0.102	0.096	1.138	1	0.286	1.107
Time	−0.025	0.010	6.408	1	0.011	0.975
Constant	7.717	3.174	5.911	1	0.015	2,246.879

Abbreviations: EOR, extent of resection; HB, House–Brackmann; KPS, Karnofsky performance status.

Note: Binary logistic regression with duration (minute) and maximum diameter (mm) as continuous covariate and experience as categorical covariate to predict three outcomes: EOR (total vs. subtotal), definitive KPS (>90 vs. <90), and definitive facial status (HB > 2 vs. HB < 2).

Table 7 A two-sample t-test to compare the two different samples (2012 vs. 2014) for the continuous covariates

Data	Exp	N	Mean	Standard deviation	p-Value
Meningiomas					
Time	0.00	13	471.5385	155.98323	0.085
	1.00	13	375.0000	115.03623	
Diameter	0.00	13	37.5385	7.58964	0.659
	1.00	13	38.9231	8.21037	
Schwannomas					
Time	0.00	16	494.0625	108.27771	0.008
	1.00	15	383.1333	110.02653	
Diameter	0.00	16	32.5625	5.97739	0.499
	1.00	15	30.8667	7.76316	

Note: Operative time seems shorter in the second period of the series.

management path. Similarly, they should be able to deeply understand the peculiarities of different CPA tumors and differentiate them based on volume, location, biology, etc. All these notions should systematically be coupled to patient outcomes by attending outpatient clinics. On the other hand, there are issues related to specific surgical complexity, manual dexterity, and techniques. Trainees should develop knowledge of regional anatomy through repeated attendance in anatomy laboratories and take advantage of modern three-dimensional neuroimaging modeling and simulation. Three-dimensional reconstruction allows the simulation of the various surgical approaches to understand their limits and benefits, and facilitates the selection of the most appropriate approach for each case.³⁴ Furthermore, manual dexterity should be progressively enhanced through the application of microsurgical techniques for vascular and neural manipulation and the constant use of surgical microscopes and microinstruments in every single tumor case, starting from superficially seated pathologies and progressing to deeper, more complex tumors.

Limitations and Conclusion

The global decrease in CPA tumors that are considered suitable for surgical resection and the rise of radiosurgery have raised questions regarding the training of new skull-base surgeons. The presented series has the limitation of being limited to a restricted numbers of patients, of having a retrospective design and of gathering schwannomas and meningiomas. However, it has the merit to deal with a poorly analyzed aspect of the CPA surgery, that is, the learning process in an extremely delicate field of neurosurgery. A thorough and well-structured training process, a mentorship-based environment, and exploitation of modern microsurgical and neurophysiological techniques can yield satisfactory results, even in the case of large CPA tumors operated on by new skull-base surgeons.

Table 8 Synopsis of recent works dealing with large meningiomas and schwannomas of the CPA

Author	Pathology	Gross-total and near-total resection	Subtotal resection	Facial nerve definitive status (HB)
Nakamura et al (2005)	421 meningiomas of all size	86%	14%	88.9% HB 1–2
Jiang et al (2006)	56 meningiomas > 3 cm	79%	21%	67.9% HB 1–2
Leonetti et al (2006)	29 meningiomas > 3 cm	67%	nr	89% anatomical preservation
D'Amico et al (2017)	51 meningiomas of the CPA > 2.5 cm	67%	33%	89.5% facial nerve function unchanged or improved
Daming et al (2014)	37 schwannomas > 4 cm	94.6–2.7%	nr	81.1% HB 1–2
Liu et al (2015)	106 schwannomas > 3 cm	82%	14%	78% HB 1–2
Harati et al (2017)	49 schwannomas grades 4a and 4b	83–15%	2%	69% HB 1–2
Boublata et al (2017)	151 schwannomas 3–6 cm	83%	17%	82% HB 1–2
Bernardeschi et al (2017)	25 schwannomas 3–6 cm	100% near total	nr	84% HB 1–2
Spena et al (2017)	31 schwannomas 26 meningiomas (>26–51 mm)	67.7–29% 69.2–19.2%	3.2% 11.5%	64.5% HB 1–2 80.7% HB 1–2

Abbreviations: CPA, cerebellopontine angle; HB, House–Brackmann.

Note: Principal outcome measures such as extent of resection and postoperative facial status are reported.

Notes

1. Radiosurgery for small-to-medium size schwannomas and meningiomas of the CPA have raised questions regarding the training of new skull-base surgeons.
2. The learning curve for this surgery is steep and requires early interest and dedication by the residents and younger surgeons.
3. Satisfactory results can be achieved in the hands of younger skull-base surgeons if these are specifically trained.
4. Trainees interested in this type of surgery should attend high-volume centers for CPA tumor cases and learn the entire management path.
5. They should take advantage of anatomy laboratories and modern three-dimensional neuroimaging modeling and simulation which also allow for visualization of various surgical approaches.
6. Manual dexterity should be progressively enhanced through the application of microsurgical techniques for vascular and neural manipulation and the constant use of surgical microscopes and microinstruments in every single tumor case, starting from superficially seated pathologies and progressing to deeper, more complex tumors.

Conflict of Interest

The authors declare no conflict of interest.

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