Predictors of Hearing Functional Outcome following Surgery for Cerebellopontine Angle Meningioma.

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Abstract

OBJECTIVE

Cerebellopontine angle (CPA) meningioma can affect hearing function and require expeditious treatment to prevent permanent hearing loss. The authors sought to determine the factors associated with hearing functional outcome in CPA meningioma patients treated with surgery and/or radiation therapy either stereotactic radiosurgery or stereotactic radiation therapy.

METHODS

Consecutive patients with CPA meningioma who had presented at our hospital from 2008 to 2018 were identified through retrospective chart review. Hearing function-pure tone audiogram (PTA) and speech discrimination score (SDS)-was assessed before and after surgery for CPA meningioma. Hearing function with PTA>50 dB and SDS<69% were defined as poor hearing functional outcome. Multivariable Cox Proportional Hazards Regression model was used to assess the associations between pre-operative hearing functional assessment and post-operative hearing functional outcomes.

RESULTS

The study cohort included 31 patients (80.6% females, with a mean age of 61.3±15.2 years) with a median clinical follow-up of 5 months (range, 1 week-98 months). The mean pre-operative PTA and SDS were 23.8±11.2 dB and 64.4±22.2% respectively. At the last visit, there was a significant hearing recovery, with an improvement of 29.7±18.0 dB ($p<0.001$) and 87.6±17.8% ($p<0.001$) in PTA and SDS respectively. Multivariable cox proportional hazards regression model was conducted after adjusting for age, gender, tumor volume, location, and classification of the tumor, which revealed that patients undergoing surgery through retro sigmoid approach [Hazards Ratio (HR): 32.1, 95% Confidence Interval (CI): 2.11-491.0, $p=0.01$] and gross total resection (GTR) (HR: 2.99, 95%CI: 1.09-9.32, $p=0.05$) had significantly higher risk of poor hearing functional outcome. Moreover, patients with poor preoperative hearing had 85% higher chances of poor hearing functional outcome post operatively (HR: 0.15, 95%CI: 0.03-0.59, $p=0.007$).

CONCLUSION

Postoperative improvement in hearing is a reasonable expectation following surgery for CPA meningioma. Preoperative hearing, surgical approach and extent of surgical resection are predictive of postoperative hearing function outcome and can identify patients at higher risk of hearing loss.

Introduction

Cerebellopontine angle (CPA) meningiomas constitute 6-15% of the tumors in CPA [1], and 1.5% of all intracranial meningiomas. Despite the advancement in the surgical techniques and tools, CPA meningioma stills poses formidable challenges. These slow growing tumors may infiltrate the anatomy and critical neurovascular structures, which in turn hampers the chances for complete surgical resection. Of the meningiomas that occur in the CPA, a minority will invade the dura of the internal auditory canal (IAC). Whether the canal is involved is significant because removal of tumors involving the IAC potentially exposes the facial nerve and cochlear nerve to increased risk of injury during surgical tumor removal. In terms of preservation of hearing function in CPA meningioma, previous studies have suggested that surgery should always be considered regardless of pre-operative hearing status [2].

No previous studies have determined the predictive factors for hearing functional outcome in CPA meningioma. In this study we aimed to evaluate the predictive value of various pre- and perioperative factors, including demographics, tumor characteristics, surgical approaches, and initial hearing test assessment, for postsurgical hearing functional outcome in CPA meningioma. Understanding these factors is paramount in choosing the best surgical strategy for the patient.

Methods

Study Population and treatment:

Retrospective chart review of a prospectively maintained database was conducted for the patients with CPA meningioma treated between December 2008-January 2018. We included adult patients with meningiomas arising from the CPA and causing hearing impediment. We excluded patients with tumors confined to IAC alone, surgeries for multiple tumors (e.g., NF-2), and those with incomplete data in hearing assessment. The study was approved by the House Clinic Institutional Review board (IRB# SV-018-21); furthermore, patient consent was not needed as it was a retrospective study with non-identifiable patient data.

All cases were operated by experienced and specialized neurosurgeon at our institution, with surgical approaches depending upon the tumor location, volume, and clinical judgment. Extent of resection was based on post-operative imaging and was assigned also a modified Simpson grade in accordance with operative findings. All imaging studies, including pre-operative imaging and last follow-up imaging, were reviewed by an outside (independent) neuro-radiologist. Tumor volumes were estimated as elliptical volumes based on cranio-caudal, transverse, and anterior-posterior linear measurements.

Hearing Examination:

Audiological hearing classification was performed according to American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) recommendations, with pure tone average (PTA) calculated using thresholds at 0.5, 1.0, 2.0 and 3.0 kHz and speech discrimination score (SDS) testing performed at optimal threshold.

The hearing test was performed by an audiologist before and after surgery. As per the hospital policy, an immediate hearing test was performed after surgery to identify any hearing changes; however, we only considered data from the last follow up. Patients usually underwent clinical and radiographic follow up at 6-months, 1-year, and 1.5 years after surgery.

Surgical management:

Patients underwent surgery with a skull-base team approach consisting of neurotologic surgeon and neurosurgeon for every case, regardless of whether retro sigmoid or petrosal approach was utilized. Intraoperative facial nerve electromyography was performed using a NIMM 3 nerve monitoring system (Medtronic®, Minnesota, USA). When hearing preservation was attempted, intra-operative auditory brainstem response recording was performed.

Statistical methods

Demographic, clinical and surgical characteristics are summarized as counts and percentages for categorical and as means with standard deviation for continuous parameters. Cox proportional hazard regression model was conducted to determine the effect of various pre- and peri-operative factors, as well potential confounders (e.g., age, gender, tumor volume, surgical approach), on post-surgical outcome measures, which include PTA and speech discrimination. Our classification of good and poor hearing outcome was based on the AAO-HNS criteria. Accordingly, an individual is considered to have good outcome if the SDS is ≥69% and PTA ≤50 dB, whereas SDS<69% and PTA>50 dB belongs to poor hearing outcome. Moreover, we defined hearing improvement as 1-grade improvement in the hearing function test in the postsurgical period compared to presurgical status. For each outcome, parameters were considered significant at 0.10 alpha level on univariable analysis and then were entered into a cox proportional hazards regression model. We considered 0.05 alpha level to be statistically significant. IBM SPSS statistics software version 23.0 (IBM Corp.) was used to perform all the analysis.

Results

A total of 31 patients which include 6 males (19.4%), 25 females (80.6%) met study inclusion criteria (see Table 1). Patients ranged in age from 20 to 91 years (mean 61.3±14.0 years) at time of presentation.

Clinical and Imaging Presentation

A total of nineteen patients (61.2%) presented with sensorineural hearing loss. Nineteen patients also presented with vestibular complaints including non-specific dizziness/imbalance (n=15, 48.4%), and vertigo (n=4, 12.9%). Additional presenting symptoms included tinnitus (n=5, 16.1%), facial numbness (n=5, 16.1%), headache (n=5, 16.1%), facial pain, diplopia, impaired gag/ palate deviation, and venous infarct (n=1, 3.2% each). Two patients' tumors (6.5%) were discovered incidentally. Two patients (6.5%) had prior treatment (both had craniotomy, one had Gamma Knife radiosurgery as well). Both of these patients experienced hearing loss at the time of prior treatment.

Origin of tumor and relationship to meatus of IAC

Tumors were classified by their relationship of the center of mass of the tumor relative to the meatus of the internal auditory canal (Figure 1). Tumors were categorized as either retro-meatal (n=13. 14.9%), pre-meatal (n=9, 29.1%), infra-meatal (n=5, 16.1%), or supra-meatal (n=4, 12.9%). Retromeatal tumors originated from the posterior petrous ridge (n=11, 35.5%), or the posterior lip of the IAC (n=2, 6.5%). The nine pre-meatal tumors (29.1%) were all petro-clival meningiomas with extension into the CPA. Infra-meatal tumors included jugular foramen meningioma (n=3, 9.6%) and meningiomas of the foramen magnum with significant rostral extension into the CPA (n=2, 6.5%). Supra-meatal tumors originated from the superior lip of the IAC (n=3, 9.6%) or the tentorium (n=1, 3.2%).

Choice of Surgical Approach

Surgical approaches were chosen with the goal of providing the most direct route to the bulk of the tumor, avoiding the need to traverse the VII-VIII nerve complex in those cases for which hearing preservation was to be attempted. Patients with pre-operative anacusis (n=3, 9.6%), or for whom hearing preservation was not attempted (n=3, 9.6%) were generally treated using a petrosal approach.

A retro-sigmoid approach was utilized more commonly than any other approach (n=12, 38.7%) and was the procedure of choice for lesions located along the petrous ridge posterior to the IAC (i.e., ‘retro-meatal’ tumors). One retro-meatal tumor was removed nevertheless via a retro-labyrinthine approach. This latter patient had a small tumor causing predominantly vestibular symptoms felt due to compression of the endolymphatic sac. Retro-labyrinthine resection (n=1, 3.2%) was believed to be adequate for Simpson grade I resection and sac decompression. Pre-meatal tumors (i.e., petro-clival meningioma) in which hearing preservation was attempted were approached via combined petrosal approach (i.e., extended middle fossa/ retro labyrinthine) (n=12, 38.7%). The choice of hearing preservation approach for tumors located predominantly inferior to the meatus with extension superiorly into the CPA depended on patency of the jugular vein. Patients with a patent jugular were approached via a standard far-lateral approach (n=3, 9.6%); those with jugular obstruction (i.e., jugular foramen meningioma) were approached via a modified trans-jugular craniotomy (n=3, 9.6%). Modifications to the standard trans-jugular approach included fallopian bridge technique for skeletonization of the facial nerve (in lieu of rerouting) and maintenance of the patency of the external auditory canal in one patient. Three patients with small tumors confined to the superior lip of the IAC and the supra-meatal temporal bone were approached via a standard extended middle fossa approach. One patient with a tentorial meningioma extending into the IAC from the tentorium in an elderly female was approached via retro sigmoid craniotomy, as age >65 is a relative contraindication for middle fossa approach in our practice.

Hearing Outcomes

Twenty-six patients with measurable hearing on formal pre-operative audiometry were analyzed with regard to hearing outcome. Five patients presented with ‘dead’ ears. One additional patient who presented acutely denied pre- or post- operative hearing impairment but had no pre- or post- operative audiometry

and was therefore excluded from further hearing analysis. Of the 26 patients with pre-operative audiometry, 16 presented with AAO-HNS class A hearing, six with class B hearing, one with class C hearing, and three patients with class D. Hearing preservation was attempted in twenty-one patients including all patients with Class A hearing and five patients with class B hearing; hearing 'salvage' was attempted in two patients with class D hearing. Hearing preservation was not attempted in three patients with measurable hearing on audiometry: two patients with non-serviceable pre-operative hearing and giant petro-clival meningioma were approached via trans-otic and trans-cochlear approaches, and one patient with Class B hearing with meningioma eroding through the middle ear and external auditory canal underwent a blind sac closure of the ear causing a maximal conductive hearing loss.

Post-operative audiogram was performed among the patients with a median follow-up of five months (range, 1 week to 98 months). Serviceable hearing (i.e., Class A or B) was present in 21 (21/26, 80.7%) patients with formal audiometric testing. Poor outcome (i.e., Class C or D) was present in the 5 patients (5/26, 19.3%). 5 patients (5/31, 16.1%) remained deaf pre- and post-operatively. The mean pre-operative PTA and SDS were 23.8±11.2 dB and 64.4±22.2% respectively. At the last visit, there was a significant improvement in recovery, with an improvement in 29.7±18.0 dB ($p<0.001$) and 87.6±17.8% ($p<0.001$) PTA and SDS respectively.

Pre- and Post-operative audiometry are summarized in scatterplot format after the method of Gurgel et al in accordance with 2012 AAO-HNS minimal reporting standards (Figure 2) [3]. Ten patients had improved pure tone average (43%), and eight patients had improvement in speech discrimination scores (35%, See Figure 2). A total of ten patients changed AAO-HNS hearing class after surgery. Five patients had audiometric evidence of worsening hearing AAO-HNS hearing class, including three patients who lost serviceable hearing (one from A to D, and two from A to C) and two patients who went from Class A to B. Five patients demonstrated improvement of AAO-HNS hearing class post-operatively, including four patients who presented with class B hearing and one with Class D hearing, all of whom had class A hearing at the time of last follow up audiometry.

Multivariable cox proportional hazards regression model was conducted after adjusting for age, gender, tumor volume, location, and classification of the tumor which revealed that patients undergoing retro sigmoid approach [Hazards Ratio (HR): 32.1, 95% Confidence Interval (CI): 2.11-491.0, p=0.01] and GTR (HR: 2.99, 95%CI: 1.09-9.32, p=0.05) had significantly higher risk of poor hearing functional outcome. Moreover, patients with poor preoperative hearing had 85% higher chances of poor hearing functional outcome post operatively (HR: 0.15, 95%CI: 0.03-0.59, p=0.007). (Demonstrated Table 2)

Tumor Size and Extent of Resection

Mean tumor sizes as determined by maximal linear dimension based on pre-operative MRI was 2.9cm +/- 1.3cm, with a range of 1.1 to 5.5 centimeters. Mean estimated tumor volume (based on pre-operative imaging on 29 patients) was 13.1cc +/-14cc with a range of 0.65 - 37.9cc. Extent of resection was based on both operative findings and interpretation of post-operative MRI (Figure 3). Post-operative MRI was available for review in 28 patients. MRI follow up ranged from 2 days to 119 months (mean 37.6

months). Gross total or near total resection was achieved in twenty-five patients (83.9%) and sub-total resection was performed in five patients (16.1%). Sub-total resection was more common in pre-meatal meningiomas (3/9) and was significantly associated with tumor volume (p=0.02). Simpson grade of resection was assessed based on operative findings in conjunction with post-operative MRI; 22 patients (71.0%) were either Simpson grade 1 or 2, 3 grade 3 and 9 (29.0%) grade 4.

Complications and Recurrences

As described above, there was one peri-operative mortality in an elderly patient who presented with a large venous infarct of the posterior fossa. There was one additional (non-neurologic) mortality in the follow up period (24 months after surgery). Complications of surgery occurred in 10 patients (33%), including cranial neuropathy, brachial plexopathy, CSF leak, and hydrocephalus (see Table 3). Cranial neuropathies included vocal cord paralysis (n=3, 9.6%), accessory nerve injury (n=1, 3.2%), trochlear nerve paresis (n=2, 6.5%), trigeminal neuropathy (n=1, 3.2%). There were no new instances of facial nerve weakness except in one patient who had anterior transposition of the facial nerve. Vocal cord paresis was successfully managed in two patients with medialization and one patient required gastrostomy feeding. Lower cranial nerve deficits were associated with inframeatal tumors. Hearing loss was not associated with tumor location relative to the IAC.

There were three recurrences. One patient with petro-clival meningioma who underwent sub-total resection was observed to have recurrent tumor growth 36 months after surgery; this patient underwent hypo-fractionated stereotactic radiosurgery without further complication. Stereotactic radiosurgery for residual tumor was recommended in another patient undergoing sub-total resection for jugular foramen meningioma extending into the neck. A third patient underwent near total resection of a large petro-clival meningioma and experienced symptomatic recurrence at the posterior clinoid process requiring orbito-zygomatic craniotomy for resection. A fourth patient developed an enlarging arachnoid cyst at the site of surgery and underwent revision surgery for fenestration of the same eight years after her original surgery for meningioma.

Pathology

Pathology was confirmed as WHO grade 1 meningioma in 30 cases. One patient had WHO grade III meningioma. This patient received a gross total resection of tumor with coagulation of the dura and was followed with serial MRI; follow up MRI at 32 months shows no evidence of disease without adjuvant treatment. There were no atypical/ WHO grade II meningiomas identified.

Discussion

Meningiomas involving the CPA are relatively rare, constituting 5-10% of all intracranial meningiomas. Although the majority of CPA meningiomas likely do not involve the IAC, the incidence of involvement of IAC dura is not well established. For example, Agarwal et al. presented 34 cases of CPA meningioma of which 14 (41%) extended into the IAC [4]. Similarly, in their review of 519 consecutive meningiomas of the CPA, Gao et al. found that only 71 out of 193 tumors analyzed were found to have IAC involvement (37%)

[5]. In contrast, Roser et al found that only 72 out of 421 meningiomas of the CPA involved the IAC (17%) [6].

In this report we describe our experience with CPA meningiomas involving the dura of the internal auditory canal and impact on hearing functional outcome postoperatively. There are relatively few reports in the literature exclusively describing CPA meningiomas involving the dura of the IAC (See Table 4);[7] while several more reports provide sufficient detail to analyze different regions. This is important because tumors with IAC involvement have been shown to be less amenable to gross total resection and carry a higher risk of post-surgical hearing loss. Our results support basing the approach for these tumors on the anatomic relationship of the origin of the tumor to the IAC.

Taxonomy of CPA meningioma

Several groups have proposed classification of CPA tumors that specifically describes tumors relative to their IAC involvement with the goals 1) of assisting with approach determination and 2) facilitating comparison of surgical results (i.e., the expected risks of cranial neuropathy from infra-meatal tumors are different than supra-meatal tumors, etc.). These classifications can be broadly dichotomized into those that follow Desgeorges and Sterker's classification,[8] or a more simple delineation between pre- meatal and post-meatal tumor [9, 10]. Schaller et al (1999) classified CPA meningiomas as either pre-meatal or retro-meatal with regard to the risks associated with the retrosigmoid approach. They argued that the given the facial and vestibulocochlear nerves are displaced in a predictable manner by tumor growth, "pre-meatal" tumors would be expected to displace these nerves posteriorly and hence complicate tumor resection when performed by a retrosigmoid approach. We agree with these authors, however, they did not consider tumors that arose chiefly above the IAC or below it, nor did they include alternate approaches such as middle fossa or far lateral approaches in their algorithm. Therefore, following Bassiouni et al, we have incorporated "supra-meatal" and "infra-meatal" categorizations of CPA tumors to fully characterize the four cardinal points by which tumors may approximate the IAC [11].

Choice of Approach

The ideal approach for tumors of the CPA is controversial. Suboccipital/ retrosigmoid approaches are most commonly employed in most case series and constitute a plurality of approaches utilized in the present series. Some authors have reported good results exclusively utilizing the retrosigmoid approach [6, 11, 12]. Other approaches to these tumors reported in the literature include trans-petrosal approaches (including translabyrinthine, transcochlear, combined petrosal, extended middle fossa / 'Kawase' approaches, etc.), the far lateral approach for jugular foramen and foramen magnum tumors extending into the CPA, and staged retrosigmoid and orbito-zygomatic approaches for petroclival tumors [13–18]. Petrosal approaches (as opposed to retrosigmoid) have been widely used in the resection in of CPA meningiomas [4, 7, 7, 17, 19, 20]. Petrosal approaches have been criticized by some authors as either unnecessary or as incurring high risk, and excellent results have indeed been obtained by centers utilizing the retro-sigmoid approach almost exclusively [6, 9].

Several authors have argued for an “evolution” away from trans-petrosal approaches in favor of the sub-occipital/ retrosigmoid [13]. We agree that hearing-sacrificing petrosal approaches (e.g., translabyrinthine approach) should be avoided if possible. On the other hand, given that the cardinal determinant of risk to the cranial nerves is the relationship of the tumor origin to the meatus of the IAC, this risk may be mitigated by providing a surgical corridor that provides maximal tumor exposure and minimizes having to resect tumor with the cranial nerves in the foreground of the operative field. In addition, hearing preserving petrosal approaches (e.g., the extended middle fossa and combined petrosal approaches) for pre-meatal and supra-meatal tumors have the advantages of providing a shallower operative field, superior illumination, and the ability to significantly devascularize the tumor prior to tumor debulking during the drilling of the petrous bone and obviating the need for pre-operative embolization (none of our patients underwent embolization). We contend that petrosal approaches are therefore indicated for either supra- or pre- meatal tumors with IAC involvement in patients with good hearing, and in most patients without pre-operative hearing.

Hearing preservation and improvement

Hearing improvement after resection of some meningiomas has been previously reported by multiple authors [10, 11, 16, 21]. We present the first detailed audiometric analysis of hearing preservation in the literature for the treatment of CPA meningioma and predictors following the recommendations of AAO-HNS for the reporting of hearing preservation following surgery for acoustic neuroma [3]. We demonstrated that over 40% of patients undergoing hearing preservation surgery experienced audiometric improvement on post-operative audiometric testing, though only five patients had sufficient improvement to change AAO-HNS hearing class. However, most of our patients presented with class A hearing, such that only seven patients were included in our analysis who had class B-D hearing (and therefore eligible to improve AAO-HNS hearing class). The overall hearing class improvement rate for patients presenting with class B or worse hearing was 5/7 (71%). On the other hand, of the sixteen patients who had class A hearing, five experienced a worsening of hearing by at least one grade (5/16, 31%), three of whom lost serviceable hearing (3/16, 19%). We interpret this data to mean that patients with impaired hearing (AAO-HNS class B or worse) may reasonably be advised that hearing may improve after surgery for removal of CPA meningioma, but those with essentially intact hearing have a significant risk of experiencing post-operative hearing loss. These data in any event represent an aggressive effort to preserve hearing, even in patients presenting with profound hearing loss. Hence, consideration for preserving hearing was given to those patients presenting with measurable hearing believed to be ‘salvageable’. This latter group is distinct from patient with ‘serviceable hearing’ in that it reflects the possibility for improvement in hearing following tumor resection for meningioma (as opposed to acoustic neuroma, in which preservation can be achieved but hearing improvement is rare). This includes some patients with AAO-HNS Class C or even D hearing. Hearing sacrificing approaches, including translabyrinthine and transcochlear approaches, such as those used by some authors should be avoided whenever possible. We attempted hearing preservation surgery whenever we felt it to be technically feasible, without excluding patients purely on basis of preoperative audiogram. Hearing preservation was not attempted based on anatomic factors, such as for a patient in which the middle ear space was obliterated by tumor and the best possible

surgical outcome results in a maximum conductive loss. These patients may be considered for auditory rehabilitation with bone anchored hearing aids, and so preservation of the cochlea and cochlear nerve is nevertheless still advised. Our data supports attempting hearing preservation in nearly all circumstances other than a ‘dead’ ear.

Limitation of this study

This study is limited in its broader applicability by its retrospective design, small number of cases, and single institution bias.

Conclusion

We believe that the goal of surgery for CPA meningioma should be maximal resection of tumor consistent with preservation of cranial nerve function; this may lead to a near-total or subtotal resection. Hearing improvement after resection of CPA meningiomas in either PTA or speech discrimination may be more common than is previously reported. Preservation of hearing should therefore be attempted whenever possible, even in patients with poor pre-operative hearing. The choice of surgical approach should take into account the relationship of the meatus of the IAC with the epicenter of tumor. Our data suggest that retro sigmoid approach and complete resection of the tumor are associated with poor hearing functional outcome.

Abbreviations

Cerebellopontine angle
CPA
Internal Auditory Canal
IAC
Pure tone audiogram
PTA
Speech discrimination score
SDS
GTR
Gross Total Resection
STR
Sub total Resection
NTR
Near Total Resection.

Declarations

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Tables

Table 1: Clinical and imaging presentation of 31 patients with CPA meningioma.

Parameters	N (%)
Demographics	
Gender	
Male	6 (19.4)
Female	25 (80.6)
Age (M±SD)	61.3 (15.2)
Tumor Volume (cm^3) (M±SD)	13.1±14.0
Presenting signs/symptoms	
Sensorineural hearing loss	19 (61.2)
Imbalance/ dizziness	15 (48.4)
Vertigo	4 (12.9)
Headache	5 (16.1)
Facial numbness	5 (16.1)
Facial pain	1 (3.2)
Diplopia	1 (3.2)
Impaired gag and deviated palate	1 (3.2)
Venous infarct	1 (3.2)
Incidental	1 (3.2)
Location of the Tumor	
Foramen Magnum	2 (6.5)
Jugular Foramen	3 (9.6)
Petro clival	9 (29.1)
Posterior Lip of IAC	2 (6.5)
Posterior Petrous Ridge	11 (35.5)
Superior Lip of IAC	3 (9.6)
Tentorium	1 (3.2)
Classification of the Tumor	
Inframeatal	5 (16.1)

Premeatal	9 (29.1)
Retromeatal	13 (41.9)
Suprameatal	4 (12.9)
Surgical Approach	
Far Lateral	6 (19.4)
Combined	12 (38.7)
Retrosigmoid	12 (38.7)
Retrolabryinthine	1 (3.2)
Extent of Resection	
Subtotal Resection	5 (16.1)
Near Total Resection	6 (19.4)
Gross Total Resection	20 (64.5)
Simpson Grade	
1	10 (32.3)
2	8 (25.8)
3	4 (12.9)
4	9 (29.0)

M=Mean, SD=Standard Deviation

Table 2: Independent Predictors of Hearing Functional Outcome illustrated by Univariable and Multivariable Cox Proportional Hazard Regression Model.

Parameters	Univariable*	Multivariable
Age (<60 vs ³ 60 years)	0.75 (0.17-3.39) 1.00	-
Gender (M/F)	**2.81 (0.28-27.9) 0.36**	0.82 (0.28-2.34) 0.71
Side (L/R)	**3.77 (0.03-1.10) 0.06**	0.75 (0.41-1.38) 0.37
Tumor Volume (³ 10 vs <10 cm^3)	1.14 (0.23-5.50) 1.00	-
Symptoms at Presentation		
Sensorineural Hearing Loss	1.75 (0.35-8.71) 0.69	-
Tinnitus	0.47 (0.04-4.88) 1.00	-
Imbalance	0.92 (0.19-4.31) 1.00	-
Facial Numbness	1.50 (0.21-10.7) 1.00	-
Headache	1.50 (0.21-10.7) 1.00	-
Location of the Tumor		
Foramen Magnum	**1.01 (0.50-1.85) 0.31**	3.27 (0.64-16.7) 0.15
Jugular Foramen	1.05 (0.08-13.2) 0.97	-
Petro clival	**9.00 (1.55-52.3) 0.01**	0.53 (0.08-3.40) 0.50
Posterior Lip of IAC	0.65 (0.50-0.85) 0.65	-
Posterior Petrous Ridge	**0.33 (0.05-1.97) 0.26**	1.008 (0.94-1.19) 0.83
Superior Lip of IAC	1.05 (0.08-13.3) 1.00	-
Tentorium	0.67 (0.52-0.85) 1.00	-
Classification of the Tumor		-
Inframeatal	0.47 (0.05-4.88) 1.00	-
Premeatal	**9.00 (1.55-52.3) 0.01**	0.53 (0.08-3.50) 0.50
Retromeatal	**0.22 (0.04-1.33) 0.13**	1.54 (0.54-1.89) 0.08
Suprameatal	0.67 (0.06-7.35) 1.00	-
Surgical Approach		
Far Lateral	1.06 (0.16-7.06) 1.00	-
Combined	**7.46 (1.38-40.3) 0.02**	0.40 (0.07-2.17) 0.28
Retrosigmoid	**5.13 (1.81-39.3) 0.04**	**32.1 (2.11-491.0) 0.01****
Retrolabryinthine	0.67 (0.52-0.86) 1.00	
Extent of Resection		

Subtotal Resection	**4.07 (0.56-29.7) 0.29**	0.43 (0.09-1.95) 0.27
Near Total Resection	**2.57 (0.42-15.9) 0.35**	0.41 (0.09-1.81) 0.24
Gross Total Resection	**0.21 (0.04-1.04) 0.10**	**2.99 (1.01-9.32) 0.05****
Simpson (Radical vs non-Radical)	**3.00 (0.63-14.3) 0.25**	1.22 (0.22-6.59) 0.81
Preoperative Hearing (Good vs Poor)	**46.7 (4.14-525.5) <0.001**	**0.15 (0.03-0.59) 0.007****

*p-value <0.10 considered statistically significant due to small sample size

**Cox Proportion Hazard Model after adjusting for age, gender, tumor volume, location and classification of the tumor.

±Good Hearing Preservation is described as AAO-HS Grade 1-2 and Poor as Grade 3-4-Deaf

Table 3: Complications occurred in ten patients including new cranial nerve deficits other than hearing loss. For detailed hearing outcomes (including hearing loss) see Figure 2.

Complications	**N (%)**
Vocal cord medialization	3 (9.6)
PEG tube	2 (6.5)
Brachial plexopathy	1 (positioning related) (3.2)
CSF leak	1 (3.2)
Hydrocephalus	1 (3.2)
Sialadenitis	1 (3.2)
Headache	1 (3.2)
Cognitive complaints	1 (3.2)
Symptomatic arachnoid cyst	1 (3.2)
Cranial neuropathy (other than SNHL)	
IV	1 (diplopia) (3.2)
V	1 (trigeminal neuralgia) (3.2)
VII	1 (s/p re-routing of facial nerve) (3.2)
IX/X	3 (9.6)
XI	1 (3.2)

TABLE 4: LITERATURE REVIEW

Author	Year	n	IAC extension	Surgical Approach	%GTR	Hearing preservation
				RS only		
Peraio [12]	2018	63	63	RS only	67%	87%
Roser [6]	2005	72	72	RS only	86.10%	54%
Basssiouni [11]	2004	51	7	RS only	84%	81.60%
				Petrosal +/- RS		
Agarwal [4]	2013	34	NR	RS (n=12); transpetrosal/ condlyar (n=22)	55.90%	100%
Peyre [7]	2012	53	27	transpetrosal (n=30)	72%	77%
Deveze [20]	2007	43	32	multiple transpetrosal	79.1	55%
Sanna [22]	2007	81	28	translabyrinthine (n=27); RS (n=1)	89%	NA
Leonetti [17]	2006	29	NR	combined petrosal (all)	67%	NA
Wu [10]	2005	82	NR	RS (n=64), petrosal approaches (n=18)	83%	66%
Batra [19]	2002	21	NR	Translabyrinthine & RS (NOS)	90%	91%
Author	Year	n	IAC extension?	Surgical Approach	%GTR	Hearing preservation
				RS only		
Peraio[16]	2018	63	63	RS only	67%	87%
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Peyre[17]	2012	53	27	transpetrosal (n=30)	72%	77%
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Sanna[19]	2007	81	28	translabyrinthine (n=27); RS (n=1)	89%	NA

Leonetti[12]	2006	29	NR	combined petrosal (all)	67%	NA
Wu[22]	2005	82	NR	RS (n=64), petrosal approaches (n=18)	83%	66%
Batra[4]	2002	21	NR	Translabyrinthine & RS (NOS)	90%	91%

IAC= internal auditory canal, CPA= cerebellopontine angle, RS= retrosigmoid, NOS= not otherwise specified, GTR= gross total resection, NA=not attempted

Figures

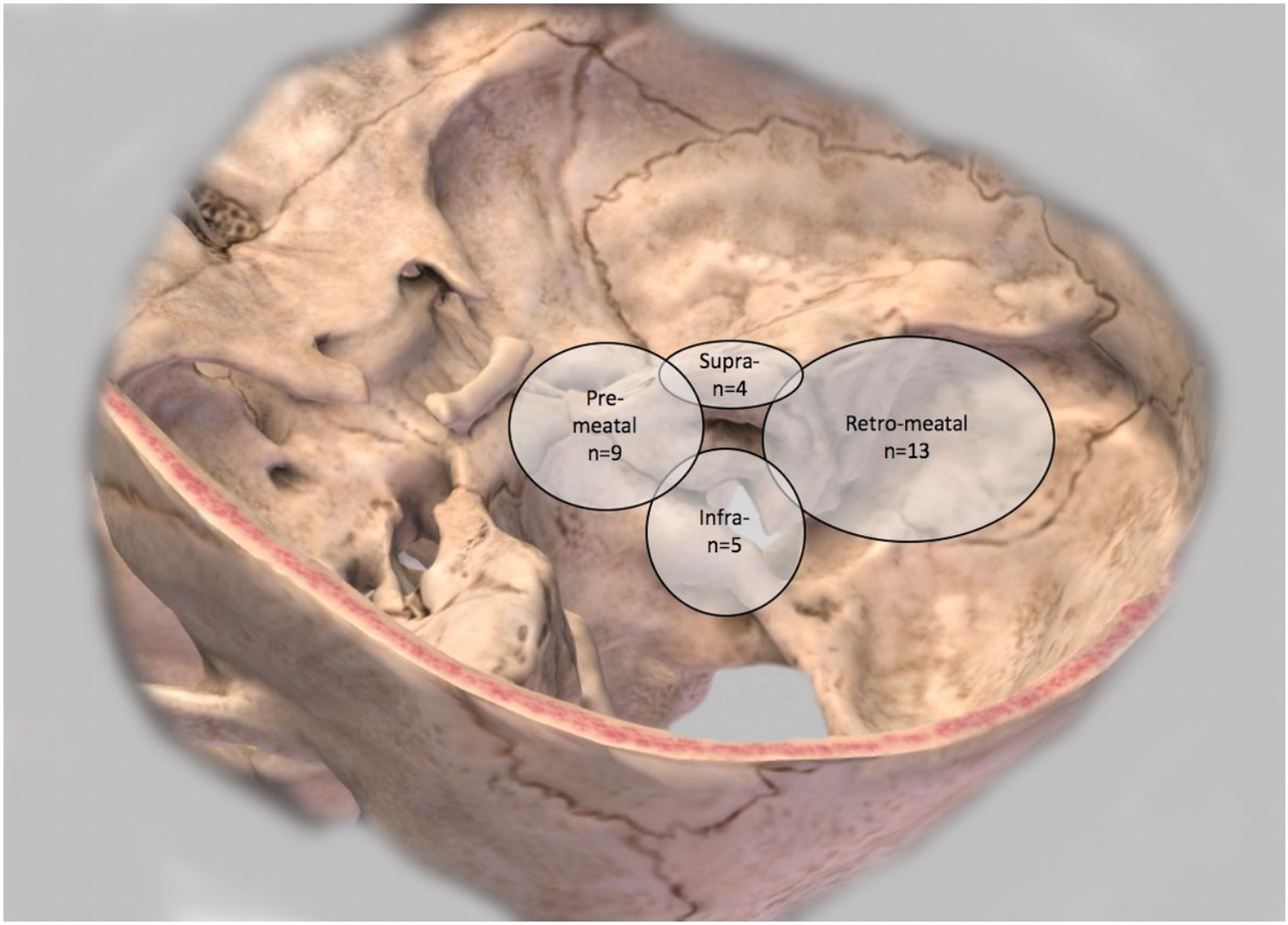

Figure 1

Tumors were classified by their relationship of the center of mass of the tumor relative to the meatus of the internal auditory canal (Figure 1). Tumors were categorized as either retro-meatal (n=13. 14.9%), pre-meatal (n=9, 29.1%), infra-meatal (n=5, 16.1%), or supra-meatal (n=4, 12.9%). Retromeatal tumors originated from the posterior petrous ridge (n=11, 35.5%), or the posterior lip of the IAC (n=2, 6.5%).

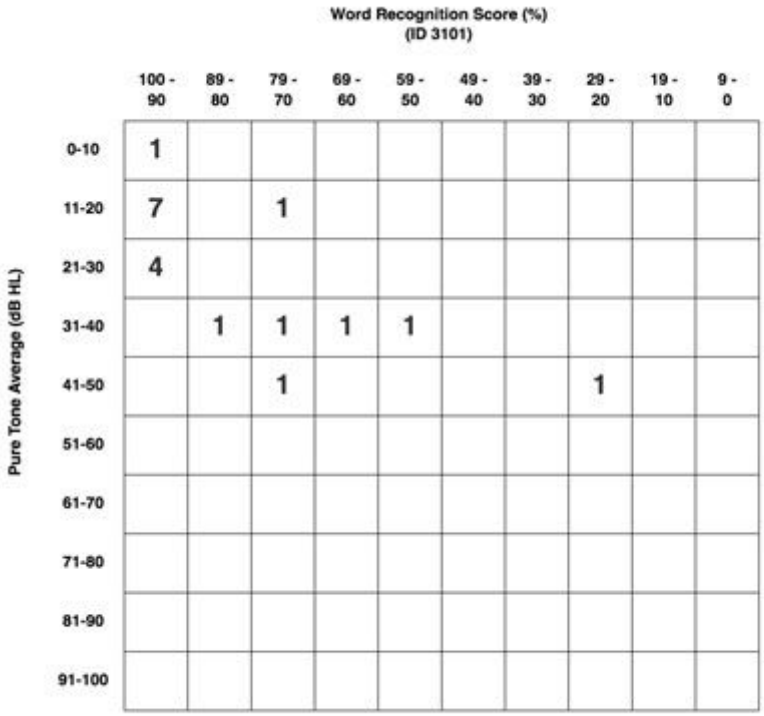

Figure 2

Pre- and Post-operative audiometry are summarized in scatterplot format after the method of Gurgel et al in accordance with 2012 AAO-HNS minimal reporting standards (Figure 2) [3]. Ten patients had improved pure tone average (43%), and eight patients had improvement in speech discrimination scores (35%, See Figure 2).

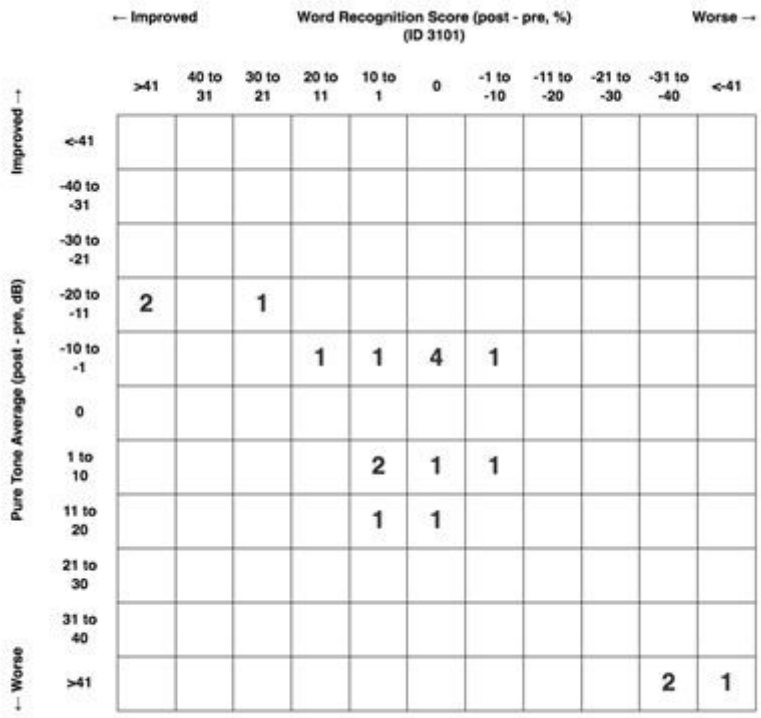

Figure 3

Mean tumor sizes as determined by maximal linear dimension based on pre-operative MRI was 2.9cm +/- 1.3cm, with a range of 1.1 to 5.5 centimeters. Mean estimated tumor volume (based on pre-operative imaging on 29 patients) was 13.1cc +/-14cc with a range of 0.65 - 37.9cc. Extent of resection was based on both operative findings and interpretation of post-operative MRI (Figure 3).