Transmastoid Partial Labyrinthectomy for Brainstem Vascular Lesions: Clinical Outcomes and Assessment of Postoperative Cochleovestibular Function

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ABSTRACT

Objectives: To discuss the transmastoid partial labyrinthectomy approach for brainstem vascular lesions, with respect to hearing and balance preservation. **Design:** Retrospective case series. **Setting:** Tertiary referral center (University Health Network, Toronto). **Participants:** Nine consecutive surgical patients between 1999 and 2004. **Main outcome measures:** Clinical, audiometric, and electrophysiological vestibular data. **Results:** Nine transmastoid partial labyrinthectomy procedures (all females) were performed. In seven patients the underlying pathology was an intra-axial brainstem cavernous malformation. Two patients were treated for a basilar artery aneurysm. All patients had progressive neurological signs. Serviceable hearing (pure tone average (PTA): < 50 dB; speech discrimination score (SDS): > 50%) was preserved in seven patients. Partial vestibular function (clinical and electrophysiological) was maintained in most patients. **Conclusions:** The partial labyrinthectomy approach to the skull base provides excellent exposure while preserving cochleovestibular function in most patients.

KEYWORDS: Partial labyrinthectomy, labyrinthectomy, brainstem cavernoma, hearing preservation, vestibular function

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Skull Base 2006;16:133–144. Copyright © 2006 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662.

Received: June 30, 2005. Accepted after revision: September 27, 2005. Published online: August 16, 2006.

DOI 10.1055/s-2006-949514. ISSN 1531-5010.

For many years, it was widely accepted that surgical disruption of the membranous labyrinth would invariably result in profound sensorineural hearing loss and balance dysfunction. Based on this premise, the traditional transpetrosal approaches to the lateral skull base and brainstem structures were considered either to preserve (suboccipital/retrolabyrinthine) or to sacrifice (translabyrinthine, transotic, and transcochlear) the labyrinth. Improved surgical access was obtained at the expense of cochleovestibular function.

In the latter part of the last century, numerous reports in the literature identified hearing preservation with accidental injury to the membranous labyrinth of the lateral semicircular canal (SCC).¹⁻³ Hakuba and colleagues⁴ and McElveen and associates⁵ first described intentional partial labyrinthine resection for surgical access to skull base tumors with some degree of residual hearing.

Parnes and McClure⁶ later reported successful hearing preservation with respect to therapeutic occlusion of the posterior SCC for recalcitrant benign paroxysmal positional vertigo (BPPV). Occlusion of the superior SCC for the treatment of pressure- or sound-induced vertigo (Tullio phenomenon), resulting from bony dehiscence of the tegmen, has also successfully preserved hearing.⁷

The concept of enhanced surgical exposure, with partial organ preservation, was further developed by Hirsch⁸ and Walsh⁹ and their associates. As an extension of a cortical mastoidectomy, the posterior and superior SCCs are sequentially occluded and isolated from the vestibule. Both the posterior and superior SCCs are then resected. The lateral SCC, endolymphatic sac, and vestibular aqueduct are carefully preserved. In combination with a petrous apicectomy, the surgical exposure allows access to neoplastic and vascular lesions of the petrous apex, clivus, brainstem, and cerebellopontine angle (CPA).

We present our series of patients who have undergone the transmastoid partial labyrinthectomy approach for the treatment of vascular lesions of the medial skull base. With anatomical preservation of the cochlear, lateral SCC and vestibule, we assessed subjective and objective hearing and balance function.

METHODS

Nine consecutive patients were reviewed retrospectively. All patients underwent transmastoid partial labyrinthectomy for surgical access to the medial skull base for the treatment of vascular lesions of the brainstem. The procedures were performed at a tertiary referral institution (University Health Network, University of Toronto) by the senior author (JAR, neurotologist) in conjunction with two staff neurosurgeons (MT, MCW).

All patients had their hearing and balance assessed pre- and postoperatively. Most patients underwent testing 12 months after surgery. Some patients underwent additional testing in the early postoperative period. Routine testing included pure tone audiometry for air and bone conduction and impedance and speech audiometry (speech recognition threshold (SRT) and speech discrimination score (SDS)). Tests for vestibular function included electronystagmography (ENG, caloric and positional) and vestibular evoked myogenic potentials (VEMPs). In some cases, a magnetic scleral search coil (MSSC) study was performed to accurately document function of the vestibulo-ocular reflex (VOR) at low- and high-frequency acceleration.

All patients were monitored intraoperatively. Brainstem evoked responses (ipsilateral and contralateral) and electrocochleography (ECoG) were used to document central auditory pathways. Electrodes were placed for trigeminal and facial nerves responses. Upper and lower limb somatosensory evoked potentials were also recorded.

Surgical Technique for Transmastoid Partial Labyrinthectomy

General anesthesia was induced and orotracheal intubation was performed. Patients were placed in the lateral position with their head stabilized in a Sugita frame. A wide postauricular skin incision was made ~3 cm behind the postaural sulcus.

The extended cortical mastoidectomy (Fig. 1) was performed with the following boundaries. The

Figure 1 Cortical mastoidectomy (left side). CN VII, facial nerve; LSCC, lateral semicircular canal; SSCC, superior semicircular canal; PS CC, posterior semicircular canal.

posterior border was formed by the sigmoid and transverse sinus, sinodural angle, and the dura of the posterior cranial fossa, 1 to 2 cm posterior to the sigmoid sinus. The superior boundary was formed by the dura of the middle cranial fossa and the tegmen from the transverse sinus to the zygomatic arch. The anterior border was formed by the posterior wall of the external auditory canal, thinned to the mastoid segment of the facial nerve. The inferior border was formed by the digastric ridge and the junction of the sigmoid sinus and the jugular bulb.

When the posterior labyrinthectomy (Figs. 2A, B) was performed, the posterior and superior SCCs were skeletonized and blulined. The ampullated end and the crus commune were fenestrated while extreme care was exerted to avoid violation of the membranous labyrinth. Suctioning of the perilymph was strictly avoided. The canals

Figure 3 Petrosectomy. CN VII, facial nerve; LSCC, lateral semicircular canal; PCF dura, posterior cranial fossa dura; MCF dura, middle cranial fossa dura; IAC, internal auditory canal.

were gently occluded with periosteum and bone wax. The posterior and superior SCCs were removed once they were isolated from the vestibule. The lateral SCC, vestibule, endolymphatic sac, and vestibular aqueduct were preserved.

In the petrosectomy portion of the procedure (Fig. 3), the internal auditory canal was skeletonized from the porus acusticus to the vestibule. The retrofacial air cell tract (inferomedial) was removed to facilitate exposure of the brainstem. All remaining bone superior, inferior, and posterior to the labyrinth, including the petrous apex, was then removed.

The presigmoid dura was opened along the medial border of the sigmoid sinus, from the jugular bulb, across the sinodural angle to the superior

Figure 2 (A) The PS CC and SSCC are skeletonized and blulined. The ampullated ends and the crus commune are identified. (B) The ampullated ends and the crus commune are fenestrated and occluded. The PS CC and SSCC are then resected. PS CC, posterior semicircular canal; SSCC, superior semicircular canal; LSCC, lateral semicircular canal.

petrosal sinus, and along the inferior portion of the temporal lobe. When required, a temporal or suboccipital craniotomy (or both) can be performed to aid exposure.

A primary dural closure was performed with or without temporalis fascia and abdominal fat obliteration. The aditus ad antrum was closed off from the mastoid cavity with small pieces of muscle and temporalis fascia. Tissue glue was applied to help prevent cerebrospinal fluid (CSF) otorrhea and rhinorrhea. The exposed air cells of the petrous apex were sealed with bone wax. A layered closure was

performed and the mastoid and head dressing secured.

RESULTS

Nine patients (all women) underwent a transmastoid partial labyrinthectomy between 1999 and 2004. Their ages ranged between 25 and 51 years (average, 36 years). The average length of follow-up was 24.3 months (range, 4 to 54 months).

Figure 4 Pre- and postoperative MRI scans of patient 7. (A) Preop T1-weighted MRI (axial). (B) Postop T1-weighted MRI (axial). (C) Preop T1-weighted MRI (sagittal). (D) Postop T1-weighted MRI (sagittal). Circled area in (B) indicates postop fascia/fat duraplasty.

Figure 5 Postoperative CT scan of patient 7. Note the outline of the preserved LSCC and labyrinth. Lat SCC, lateral semicircular canal.

All patients had progressive neurological signs. The most common findings on clinical examination were diplopia/sixth cranial nerve palsy (6), ataxia and incoordination (5), hemiplegia (4), trigeminal paresthesia (4), facial palsy (4), tinnitus/hearing loss (4), severe headache (2), and dysarthria (1).

In seven cases, the underlying pathology was an intra-axial brainstem cavernous malformation (Figs. 4 and 5). The remaining two patients had basilar artery aneurysms.

Pre- and postoperative hearing results are summarized in Table 1. Seven patients maintained serviceable hearing according to the 50/50 rule (PTA < 50 dB and SDS > 50%). These patients are classified as Class A or B, as defined by the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) guidelines for the reporting of hearing preservation for vestibular schwannoma surgery.¹⁰ The average changes in hearing across the cohort are summarized in Table 2. SDS decreased from 98% to 89%.

The results for postoperative vestibular testing are shown in Figures 6 and 7. An increase in caloric reduction was noted in seven of eight patients. Patient 7, with a 59% caloric reduction, had a high-frequency acceleration study using MSCC techniques. The patient's gain response for the horizontal VOR on the operated (right) side, for low- and high-frequency acceleration head movements, were normal (Figs. 8A, B). Postoperatively, VEMPs were recorded in two of seven patients. No response was recorded in four of seven patients. In one patient, no pre- or postoperative response was recorded.

Aside from some mild postoperative imbalance and dizziness, no patients had subjective vertigo (including BPPV) and there was no documented abnormality on clinical neuro-otological examination.

Table 1 Pre- and Postoperative Hearing Results*

Patient	PTA (AC) dB HL	PTA (BC) dB HL	HFA dB HL	SRT dB SPL	SDS (%)	Hearing Class (AAO-HNS)
1	11/ 26	11/ 14	20/ 50	15/ 20	100/ 88	A/A
2	3/ 14	3/ 6	5/ 12	10/ 15	100/ 100	A/A
3	43/—	43/—	55/—	30/—	52/—	B/—
4	110/ 110	110/ 110	110/ 110	CNT	CNT	D/D
5	8/ 13	8/ 6	12/ 7	5/ 15	100/ 96	A/A
6	1/ 10	1/ 4	2/ 18	5/ 10	100/ 100	A/A
7	3/ 15	3/ 5	7/ 8	10/ 25	100/ 88	A/A
8	11/ 8	9/ 8	10/ 28	5/ 10	84/ 92	A/A
9	8/ 50	8/ 46	20/ 62	15/ 60	100/ 60	A/B

*Postoperative values shown in **bold**.

PTA, pure tone average (0.5, 1, 2, 3 kHz); AC, air conduction; BC, bone conduction; HFA, high frequency average (4, 6, 8 kHz); HL, hearing level; SRT, speech recognition threshold; SPL, sound pressure level; SDS, speech discrimination score; CNT, unable to test; (AAO-HNS), American Academy of Otolaryngology-Head and Neck Surgery.

Table 2 Average Change in Postoperative Hearing

Parameter	dB
PTA (AC)	12
PTA (BC)	6
HFA	14
SRT	11

PTA, pure tone average; AC, air conduction; BC, bone conduction; HFA, high frequency average; SRT, speech recognition threshold.

DISCUSSION

Traditional transpetrosal approaches to the medial skull base either preserve or sacrifice hearing and balance function. The retrosigmoid/suboccipital ap-

proach preserves the labyrinth but impedes access to the anterior skull base, particularly if the sigmoid sinus is dominant or anterior. Problems also can be encountered with an anteriorly placed vein of Labbé. A significant amount of cerebellar retraction is required for optimal exposure. The translabyrinthine approach provides excellent exposure but the cost is permanent hearing loss and vestibular loss. The transotic and transcochlear approaches offer greater versatility with respect to manipulation of surgical instruments, but clival exposure is not greatly enhanced. With these procedures, the facial nerve is mobilized. The result is a degree of facial paralysis or paresis in addition to the functional effects of cochleovestibular loss.

Figure 6 Electronystagmography—caloric results. **Figure 7** Vestibular evoked myogenic potentials—results.

Figure 8 Postoperative magnetic scleral search coil results (patient 7). (A) VOR gain unity (equals 1) is preserved on the operated (right) side. (B) There is evidence of an incidental unrelated mild high frequency/acceleration vestibular deficit on the contralateral (left) side.

The transmastoid partial labyrinthectomy approach provides excellent access to the medial skull base while preserving hearing and partial balance function. It can be regarded as an example of organ preservation surgery. Anatomical cadaveric studies have demonstrated an average gain of 10.8 mm in

horizontal exposure compared with the retrolabyrinthine approach. The average angle of vision to the clival pit was 58.9 degrees. This technique allows exposure of the anterolateral brainstem; posterior cavernous sinus; clivus; Meckel's cave; basilar artery; the ipsilateral sixth, seventh, eighth, ninth, and

tenth cranial nerves; and the contralateral abducens nerve.¹¹

The largest clinical series to date, reported by Sekhar et al,¹² involved 36 patients. The lesions included 33 neoplasms (predominantly petroclival meningiomas and chordomas) and 3 vertebrobasilar aneurysms. Our series is confined to brainstem vascular lesions: intra-axial brainstem cavernous malformations and vertebrobasilar aneurysms. Although we have reported our initial results in a small series of patients with this technique,^{13,14} here we focus on the hearing and balance results.

It has been estimated that as many as 35% of intracranial cavernous malformations occur in the brainstem.¹⁵ Once symptomatic, usually after an initial bleeding episode, these lesions may cause progressive neurological morbidity.¹⁶ Recurrent hemorrhage or thrombosis may cause the lesion to expand with or without extravasation into the adjacent parenchyma.¹⁷ Rates of rebleeding range from 5% to 30% per patient year.^{16,18} Each of the seven women with cavernous malformation in this series displayed evidence of neurological deterioration after initial conservative management.

Hearing was preserved in seven of eight patients with preoperative serviceable hearing (PTA < 50 dB and SDS > 50%). The average increase in bone conduction thresholds for the speech frequencies (PTA) was 6 dB; a slightly greater threshold change was noted in the higher frequencies (14 dB). We routinely performed audiometry 12 months after surgery, although some patients underwent testing earlier. Thresholds often improved after the initial 3 months. No patient experienced long-term tinnitus. The average change in air conduction for the speech frequencies (PTA) was 12 dB. This change can be attributed to the packing of the aditus ad antrum with muscle and periosteum to prevent CSF leakage, impinging on ossicular vibration.

Our last patient complained of postoperative ipsilateral aural fullness and fluctuating hearing. Her postoperative audiogram, performed when she felt her hearing was significantly worse, revealed a moderate mixed hearing loss (PTA 46 dB, SDS

60%). Although she maintained serviceable hearing, she has features consistent with cochlear endolymphatic hydrops. It is possible that plugging of the posterior and superior SCCs or an injury to the endolymphatic duct or sac induced changes in the fluid dynamics of her inner ear.

Patient 3, who had a basilar artery aneurysm, did not complete postoperative testing. In the early postoperative period she developed hydrocephalus related to cerebellar edema, which required a ventriculostomy. As a result of overcoagulation, she later developed a large frontal subdural hematoma that required a frontal lobectomy. Retrograde thrombosis in the brainstem vascularity led to a "locked-in" syndrome and permanent quadriplegia.

Patient 4, who had a brainstem cavernous malformation, had no clinical hearing on routine preoperative pure tone audiometry. Waveforms had been normal on intraoperative ECoG and postoperative distortion product otoacoustic emission testing (DPOAE) for the frequencies of 1 to 4 kHz. We conclude that this loss was indicative of a central auditory deficit. The same patient developed a postoperative CSF leak and required re-exploration and closure. Two years later, she developed further neurological signs and was found to have rebled from an area of residual disease. Revision surgery was performed via the translabyrinthine approach.

Overall, our results compare favorably with those of Sekhar et al.¹² In their series, serviceable hearing (Gardner-Robertson Grade I or II: PTA < 50 dB and SDS > 50%) was preserved in 53% of the patients at 3 months and in 81% at 12 months. Loss of functional hearing was attributed to excessive manipulation of the cisternal portion of the eighth cranial nerve complex rather than to the partial labyrinthectomy technique per se, because most of these patients had a coexistent postoperative facial nerve weakness. The other main complication in that series was CSF leakage in 33% of the patients.¹²

With respect to vestibular function, ENG (caloric) was used as the standard objective assessment tool. This test assesses functional integrity of

the lateral SCC at low frequencies and accelerations.¹⁹ We found a further caloric reduction in seven of eight patients, despite little clinical evidence to suggest a peripheral vestibular loss in the plane of the lateral SCC. The greater caloric reduction may be explained physiologically by a reduction in the thermal gradient after the mastoid bone is removed.

In one asymptomatic patient (number 7), the caloric reduction was 59% postoperatively. An MSCC study, examining function of the VOR in the horizontal plane at high frequency and acceleration, showed normal gain. The scleral search coil study is a physiologic means of assessing minute eye movements during a wide array of frequency and acceleration head movements.²⁰ This finding highlights that function can be preserved when structural integrity of the lateral SCC is maintained.

The value of the VEMP in documenting the integrity of the otolithic vestibular system is increasingly recognized. Colebatch and associates^{21,22} first demonstrated sternocleidomastoid muscle reflexes in response to repeated high-intensity auditory stimulation of the vestibule. Localization to the inferior vestibular nerve (supplying the saccule and posterior SCC) followed.²³ The presence of VEMPs after saccular nerve preservation, during removal of a vestibular schwannoma, suggests a saccular origin.²⁴

We preserved the VEMP in two of seven patients. No postoperative response was noted in four of seven patients. Possible explanations include altered saccule function after the partial labyrinthectomy despite anatomical preservation, ossicular chain stiffness, and technical factors in performing this test. Further refinement of these techniques may improve responses in the future.

CONCLUSION

The transmastoid partial labyrinthectomy approach provides excellent exposure for the surgical

treatment of vascular lesions of the medial skull base. Preservation of serviceable hearing and partial balance function, resulting in reduced patient morbidity, further enhances the appeal of this technique.

PAPER PRESENTED

This article was presented at the North American Skull Base Society 16th Annual Meeting, April 7–10, 2005, Toronto, Ontario, Canada.

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Commentary

The authors described their experience with nine patients who underwent a transmastoid partial labyrinthectomy for brainstem vascular lesions. Previously, this procedure has been reported to preserve serviceable hearing in most patients. In my opinion, the real contribution of this article is the postoperative vestibular testing. An increase in caloric reduction was noted in seven of eight patients. Postoperative vestibular evoked myogenic potentials were also recorded, and no response was noted in four of seven patients. No pre- or postoperative response was recorded from one patient while potentials were recorded from two patients. The vestibular ocular reflex (VOR) showed normal gain, and its functionality was preserved.

This article can be added to the armamentarium of literature that justifies the safety and efficacy of this operation to access regions of the petrous apex, clivus, brainstem, and cerebellopontine angle.

Randall W. Porter, M.D.¹

Commentary

Dr. Taplin and his associates present a very nice review of a series of patients who underwent a partial labyrinthectomy to obtain access to vascular lesions of the brainstem. Their work demonstrates that careful attention to details can decrease the morbidity associated with obtaining exposure for removal of these lesions. It is encouraging that they were able to maintain serviceable hearing in seven of nine patients. Preservation of vestibular function is an interesting aspect of this

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Tel: +1(212) 584-4662.

Published online: August 21, 2006.

DOI 10.1055/s-2006-949515. ISSN 1531-5010.

study. It is hoped that preservation of vestibular function will improve overall function of clinical balance. The addition of this approach to the neurotologic armamentarium is important. Continued review of this technique and its outcomes

will help elucidate the role of this modified approach for the removal of various skull base lesions.

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10001, USA. Tel: +1(212) 584-4662.

Published online: August 21, 2006.

DOI 10.1055/s-2006-949516. ISSN1531-5010.