Tympanum reconstruction using a sternocleidomastoid flap in patients with lateral skull base lesions: surgical technique and clinical report

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1 INTRODUCTION

Lateral skull base lesions are typically benign, so surgery is the optimal treatment, and complete tumor removal is possible with surgery. Due to the anatomical complexity of the lateral skull base, modern skull base surgery involves bone removal to provide the necessary access and to prevent excessive brain retraction and cranial nerve injury.¹ The undervaluation of preserving hearing occurs due to the prioritization of protecting important
<table>
<thead>
<tr>
<th>No</th>
<th>Sex</th>
<th>Age</th>
<th>Side</th>
<th>Pathology</th>
<th>Symptom</th>
<th>Tumor size (mm × mm)</th>
<th>Involved structures</th>
<th>Ossicular chain reconstruction</th>
<th>Pre/postop FN function (HB)</th>
<th>Follow-up time (months)</th>
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<tr>
<td>1</td>
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<td>L</td>
<td>FNS</td>
<td>Palsy</td>
<td>13 × 11</td>
<td>FN(H&amp;V), inferior tympanum, mastoid</td>
<td>PORP</td>
<td>V/IV</td>
<td>41</td>
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<td>R</td>
<td>PGL from X</td>
<td>Hypotension</td>
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<td>Neck, mastoid tip, inferior wall of tympanum</td>
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<td>I/I</td>
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<td>L</td>
<td>PGL from JB</td>
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<td>Jugular foramen, inferior tympanum</td>
<td>PORP</td>
<td>I/I</td>
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</tbody>
</table>

Abbreviations: M, male; F, female; R, right; L, left; H-B, House-Brackmann grading system; FNS, facial nerve schwannoma; PGL, paraganglioma; JB, jugular bulb; ABG, air-bone gap; N, normal; FN(H&V), horizontal and vertical segments of facial nerve; FN(V), vertical segment of facial nerve.
anatomical structures such as the brain, large blood vessels, facial nerve, and lower cranial nerves; these are always considered before hearing. In most cases, even if a patient’s hearing is normal before surgery, skull base surgery causes permanent conductive hearing loss due to the closure of the external auditory canal (EAC) and eustachian tube (ET) and the destruction of tympanic structures. In modern society, along with an increase in average life expectancy, hearing has become a more important aspect of quality of life. With some skull base lesions such as facial nerve schwannoma (FNS) and paraganglioma (PGL), conductive hearing reconstruction is possible because the cochlea, ET, and middle ear mucosa are usually still in good condition.

In middle ear surgery, repair of scutum defects involves the use of conchal or tragal cartilage, autogenous bone, and titanium mesh. However, there have been few reports on the reconstruction of extensive defects of the tympanic walls after lateral skull base surgery. In this study, we assessed patients with lateral skull base tumors who underwent surgical treatment including tympanum reconstruction using a sternocleidomastoid (SCM) flap.

2 | PATIENTS AND METHODS

2.1 | Patients

This study was a single-surgeon retrospective review of a prospectively maintained database. All patients who underwent surgery for a lateral skull base pathology with tympanum reconstruction at Peking Union Medical College Hospital (PUMCH) between July 2015 and November 2017 were evaluated. The inclusion criteria were as follows: (1) patients with lateral skull base pathology involving the tympanic walls, (2) skull base surgery using an SCM flap for reconstruction of the inferior and posterior tympanic walls, and (3) cooperation with long-term follow-up. Five patients were included in our analysis. Clinical data, including age, sex, pathology, preoperative symptoms, operative procedures, pre- and post-operative hearing, and facial nerve function (assessed using the House-Brackmann [HB] grading system) were collected and analyzed (Table 1). All patients were followed up regularly. Magnetic resonance imaging or temporal bone computed tomography and pure tone tests were performed during follow-up based on clinical issues (types of pathology and onset of new symptoms). The air-bone gap (ABG) was assessed by calculating the average pure-tone air conduction thresholds at 0.5, 1, 2, and 4 kHz, minus the corresponding bone conduction thresholds. Descriptive statistics for age and follow-up time are seen as means and ranges. Review of the hospital records, imaging studies, and clinic records for all patients was approved by the ethics committee of PUMCH (Application No. S-K1162).

2.2 | Surgical technique

The surgical technique was similar to that used in a mastoidectomy or the infratemporal fossa approach (IFA), but modifications were made to preserve the tympanic membrane, partial ossicular chain, middle ear mucosa, and ET.

The procedure was as follows:

First, when creating the EAC flap, a spiral flap (described in Ugo Fisch's book) was used, to aid in preserving the flap as much as possible. A new type of mastoid retractor with a blade was used to protect the EAC flap (Figure 1A). With the use of this special retractor, the flap could be completely protected, despite the prolonged and complex operation.

Second, the tympanic membrane was preserved during surgery. The area of the tympanic membrane was preserved as much as possible because the EAC widened after the operation.

Third, the ossicular chain was preserved as much as possible. In cases where the facial nerve was displaced from the stylomastoid foramen to the geniculate ganglion, careful manipulation would have been required to preserve the stapes, which would have increased the difficulty of the surgery. In a case where only the vertical segment of the facial nerve had to be displaced, the ossicular chain was protected completely (case 4).

Additionally, the ET and cochlea were preserved, as they are essential for improving conductive hearing. Tumors located in or near the hypotympanum and posterior tympanum led to defects in the inferior and posterior walls of the tympanum; however, the cochlea, ET, stapes, tympanic membrane, and handle of the malleus were preserved (Figure 1B).

After the tumor was removed, we produced the SCM flap by detaching part of the SCM attached to the clavicle and rotating it to the reconstruction site. While cutting the SCM, the region linked to the accessory nerve was preserved. We defined this flap as the “split flap” (Figure 1C). Thereafter, we rotated the flap upwards, divided it into two parts, and placed them in the regions of the inferior and posterior walls (Figure 1D). The facial nerve was protected by the SCM flap as it was positioned between the two parts of the muscle (above the inferior part and under the posterior part).

Finally, the flap was sutured to the surrounding tissues (anterior part with the parotid tissue and inferior part...
with the jugular foramen tissue). In cases where the SCM flap was not large enough, the occipital myocutaneous flap was rotated and combined with the SCM flap for mastoid reconstruction.

In the subsequent tympanoplasty, after replacing the tympanic membrane (combined with temporal fascia), either an artificial ossicular prosthesis (PORP) or an autogenous ossicular bone (incus) was placed between the stapes and the malleus handle (in cases where the ossicular chain was not complete; Figure 2A). After meato-plasty, the EAC flap was repositioned (Figure 2B) and filled with absorbable gelatin and gauze with antibiotic ointment. The surgical procedures are illustrated in Figure 3. Two weeks after the surgery, part of the material filling in the EAC was removed under a microscope, and the patient was followed up for 1-2 weeks until the EAC was dry and re-epithelialized. Thereafter, follow-up frequency was every 1-6 months, according to the patient’s condition.

3 | RESULTS

Clinical characteristics, pathologies, symptoms, tumor sizes, involved structures, treatments, pre- and post-operative hearing, facial nerve function, and follow-up time data are shown in Table 1 for the two women and three men. The average age at the time of surgery was 40.8 years (range, 21-53 years). Four lesions were on the left side and one was on the right side. Three patients had FNS with facial paralysis and two had PGL of the head and neck. Of the patients with PGL, one had a glomus jugulare tumor with tinnitus and hearing loss, and the other had a PGL originating from the vagus nerve with hypotension. The median tumor size was
In two cases, the lesions involved both the horizontal and vertical segments of the facial nerve; in one case, the vertical segment of the facial nerve; in two cases, the inferior tympanum; in one case, the inferior wall of the tympanum; in three cases, the mastoid; in one case, the mastoid tip; in one case, the posterior tympanum; in one case, the mesotympanum; in one case, the neck; and in one case, the jugular foramen. The pre- and post-operative bone and air conduction thresholds at 0.5, 1, 2, and 4 kHz for each patient are listed in Table 2. Three patients had normal preoperative hearing and two had preoperative conductive hearing loss (CHL) with ABGs of 35 and 12.5 dB. The preoperative facial nerve function in all three patients with FNS was HB grade V. Both patients with PGL had normal preoperative facial nerve function.

**FIGURE 3** Illustrations of the surgical procedure. A, Before tumor removal, the structures were exposed; B, after tumor removal, the structures were exposed: the tympanic membrane, stapes, and cochlea were preserved, and the facial nerve was transposed anteriorly into the parotid tissues; C, the sternocleidomastoid flap was rotated upward and divided into two parts: the facial nerve was repositioned over the inferior flap and under the posterior flap; an artificial ossicular prosthesis was used to reconstruct the ossicular chain; D, the EAC flap and TM were repositioned, and the temporal fascia was combined with the TM to fix the defect. EAC, external auditory canal; ECA, external carotid artery; FN, facial nerve; ICA, internal carotid artery; IX, glossopharyngeal nerve; JV, jugular vein; PCEV, posterior condylar emissary vein; SC, semicircular canal; SCM, sternocleidomastoid; SS, sigmoid sinus; TM, tympanic membrane; X, vagus nerve; XI, accessory nerve; XII, hypoglossal nerve [Color figure can be viewed at wileyonlinelibrary.com]

**TABLE 2** The pre- and post-operative bone and air conductive hearings of 500, 1 k, 2 k, and 4 kHz

<table>
<thead>
<tr>
<th>Case</th>
<th>Pre 500 Hz</th>
<th>Pre 1 kHz</th>
<th>Pre 2 kHz</th>
<th>Pre 4 kHz</th>
<th>Pre ABG</th>
<th>Post 500 Hz</th>
<th>Post 1 kHz</th>
<th>Post 2 kHz</th>
<th>Post 4 kHz</th>
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<td>35-75</td>
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<td>0</td>
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<td>35-45</td>
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<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

*Note:* The unit of hearing is decibels. The numbers before “–” are bone conductive hearing and the numbers after “–” are air conductive hearing. If there is only one number, it means no air bone gap.

Abbreviations: ABG, air bone gap; pre, preoperative; post, postoperative.
Two of the three patients with FNS underwent surgical treatment similar to an open cavity mastoidectomy to remove the tumor, because the tumor had invaded the entire vertical segment of the facial nerve near the inferior and posterior EAC. Facial nerve reconstruction followed, using the great auricular nerve for a graft. These patients’ ossicular chains were reconstructed using a PORP in one case and the incus in the other case. The remaining patient with FNS underwent a surgical treatment similar to a partial petrosectomy, because the tumor had not only invaded the entire facial nerve but also broken the EAC. However, the ossicular chain and the middle ear mucosa were kept in place because the tumor did not invade the ossicular chain, although the stapes tendon was removed as the tumor was close to the tendon. The patient with a PGL originating from the vagus nerve underwent a partial mastoidectomy because the tumor was relatively small, and the EAC and inferior tympanum were dissected because the vertical segment of the facial nerve needed to be mobilized for tumor exposure and elimination. The ossicular chain was completely normal and intact. The patient with a glomus jugulare tumor underwent a surgical treatment similar to the infratemporal fossa type A approach to expose the tumor in the jugular foramen. The tumor was removed, and the ossicular chain was reconstructed with a PORP.

The average postoperative ABG was 14 dB (range, 0-27.5 dB). The patient with an intact ossicular chain had normal postoperative hearing. The patient with stapes tendon removal had CHL with a postoperative ABG of 25 dB. The patient with an incus for ossicular chain reconstruction had CHL with an ABG of 7.5 dB. The two patients with a PORP for ossicular chain reconstruction had CHL with ABGs of 27.5 dB (case 1) and 10 dB (case 5). The postoperative facial nerve function of the three patients with FNS remained at HB grade IV up to the last follow-up, and the facial nerve function of the two patients with PGL recovered to normal levels at 3 months after surgery. The average duration of follow-up was 24.2 months (range, 15-44 months), with no tumor recurrences or obvious atrophy of the flaps (Figure 4). Imaging of the tympanic membrane showed a normal ear canal (Figure 5A), except for one case of external canal adhesion 6 months after the surgery (Figure 5B). No atresia or adhesions were reported in the other patients. Adhesion release was performed 6 months after the surgery in the patient with external canal adhesion.

4 | DISCUSSION

Skull base surgery is performed not only to remove lesions, but also to preserve function and to reconstruct.\textsuperscript{8} Reconstruction of lateral skull base defects can involve the use of a temporoparietal fascial flap, free flap, cervicofacial flap, skin grafting, pedicled myocutaneous flap,\textsuperscript{9} and other components. Hydroxyapatite cement\textsuperscript{6} has been used for tympanum reconstruction, but it has the potential for rejection and infection. The temporoparietal fascial flap is located above the superior
tympanic wall, but it is not convenient or large enough to reconstruct the posterior and inferior tympanic walls.

We will describe the usefulness of the temporoparietal fascial flap for reconstruction of the superior and anterior tympanic walls in another article. It is relatively difficult to ensure survival of the free flap, as fat tissue is absorbed over time. Cervicofacial and pedicled myocutaneous flaps are mainly used for large skin defects, and the resulting surgical trauma is greater. In our cases, the SCM flap was sufficient for tympanum reconstruction. However, to the best of our knowledge, there have been no previous reports on the application of the SCM flap for tympanum reconstruction. The SCM flap is most commonly used to treat facial defects and to reconstruct or repair structures such as the cheek, oro- and hypo-pharyngeal walls, cervical esophageal fistulae, and laryngotracheal complex.

In this report, we described the key considerations for creating the SCM flap.

First, when cutting the SCM at its origin, the muscle fibers controlled by the accessory nerve were preserved, so that its function was protected.

Second, the flap was separated into two parts or combined with an occipital myocutaneous flap to rebuild the inferior and posterior walls of the EAC; the flap was then fixed using a silk suture.

Third, when combined with the spiral EAC flap, the SCM flap may help to form a better EAC. Several types of EAC flaps have been used for canaloplasty surgery, such as the undersurface graft, superiorly based conchal skin flap, posteriorly based flap, inferiorly based posterior meatal flap, and island flap, which require rotation of the skin outside the ear canal. The spiral flap used in this study can be applied to different kinds of pathologies and offers improved preservation of the skin of the ear canal, because it has a wide base and an abundant blood supply.

Fourth, the facial nerve can be positioned between the two layers of the flap for better protection.

Finally, an appropriate volume of SCM should be used, as EAC adhesion occurred in one of our cases due to excessive muscle volume. The required muscle volume depends on the patient's height and weight and the deficiency of the tympanic cavity, which is related to the tumor size and range. Further research is required to develop a standard for calculating the required muscle volume for each case.

In traditional skull base surgery, the ET and EAC are closed due to the extensive removal of temporal bone structures. In our cases, we preserved the EAC flap, cochlea, stapes, and ET, which remained in normal condition before surgery. We performed tympanum reconstruction rather than tympanoplasty, involving not only the reconstruction of the tympanic membrane and ossicular chain, but also the reconstruction of the tympanic walls, canaloplasty, and meato-plasty. Our approach enabled postoperative hearing preservation. Because the status of the middle ear mucosa is crucial for ensuring postoperative middle ear function and good hearing, protection of the mucosa during surgery should be a focus point.

Ventilation of the middle ear is one of the most relevant factors affecting postoperative hearing. Hearing is affected by the type of middle ear pathology, disease extent, presence of residual ossicles, and status of the middle ear mucosa. The mean postoperative ABG in our study was 14 dB. Positive hearing results in our cases may have been observed because the pathology did not influence the middle ear mucosa and the patients' ETs were normal before surgery. Consequently, postoperative ventilation of the middle ear could recover quickly after surgery. Furthermore, we sought to preserve the original structures. For example, the ossicular chain of patient 4 was completely preserved during surgery; therefore, the patient had no ABG after surgery. The incus was used for ossicular reconstruction in one patient, and a good hearing outcome (ABG 7.5 dB) was obtained, which was better than the outcomes in the two cases in which PORP was used (27.5 and 10 dB). A good hearing outcome may have been obtained in this patient because the malleus handle may not have been broken but merely moved forward. Some previous studies have shown that the malleus handle is important for hearing transmission. However, in our study, three patients' bone conduction hearing thresholds at 2 and 4 kHz showed increases of 10-20 dB, which may be due to the injury to the inner ear during surgery. When the tumor was removed, the hearing disturbance typically involved high-frequency hearing.

Although the facial nerve was displaced during surgery, the two patients with PGL of the head and neck displayed normal facial nerve function 3 months after surgery. The desire to protect the ossicular chain made the transposition of the facial nerve more difficult, because the stapes was in front of the facial nerve and space was limited. Based on our cases, we can conclude that the facial nerve is not a barrier to tympanum reconstruction, and careful displacement can lead to good results. The facial nerve recovery time in our study was less than half a year. These positive results may be because the tumors were relatively small, and the facial nerve could be freed from the fallopian canal without tumor interference or bleeding. The three patients with FNS had facial nerve function of HB grade IV after great auricular nerve graft, and the longest follow-up time was 41 months. The unsatisfactory facial nerve results may be
due to the graft nerve having been too long, with the longest being approximately 8 cm. The facial nerve tumors were giant and invaded the vertical and horizontal segments of the nerve. Some previous studies have also reported weak facial nerve function in patients who underwent facial nerve excision and grafting. The best reported result achieved was HB grade III.20

Finally, apart from the proper fixation of flaps, postoperative dressings are also important to achieve positive results. However, further removal of factors that may lead to adhesion and affect results is required. In our study, there was one case of postoperative EAC adhesion. During follow-up, we noticed that the ear canal of this patient was narrower than that of the others, and the patient was treated with adhesion release 6 months after surgery.

One limitation of our study was the small sample size. Further research is required to standardize this surgical technique and determine appropriate methods for calculating the required muscle volume and suturing the SCM flap in the correct location. Moreover, when encountering a cerebrospinal fluid (CSF) leak or potential leak during surgery, tympanum reconstruction should be avoided as it can increase the risk of a CSF leak or intracranial infection.6 The tumors in our study were all extradural, and no CSF or dura were encountered.

5 | CONCLUSIONS

During skull base surgery, tympanum reconstruction is an appropriate method to preserve hearing in patients with an intact cochlea and ET. Furthermore, the SCM flap can be used for reconstruction of the inferior and posterior tympanic walls, and it does not affect facial nerve transposition or functional recovery if performed carefully. In addition, careful postoperative dressing is necessary for good results. Further studies involving reconstruction of the superior and anterior tympanic walls should be conducted in the future (Video S1).

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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REFERENCES

SUPPORTING INFORMATION
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