

ORIGINAL RESEARCH

Impact of occlusive material and cochlea-carotid artery relation on eustachian tube occlusion in subtotal petrosectomy

Stefan Lyutenski^{1,2}  | Sabri El-Saied^{1,3} | Burkard Schwab^{1,4}

¹Department of Otorhinolaryngology, Hannover Medical School, Hannover, Germany

²Department of Otorhinolaryngology, Helios Hospital Berlin-Buch, Berlin, Germany

³Department of Otolaryngology - Head and Neck Surgery, Soroka University Medical Center, Be'er Sheva, Israel

⁴Department of Otorhinolaryngology, Helios Hospital Hildesheim, Hildesheim, Germany

Correspondence

Stefan Lyutenski, Department of Otorhinolaryngology, Hannover Medical School, Hannover, Germany.
Email: s_lyutenski@gmx.de

Abstract

Objective: To evaluate the success rate of eustachian tube (ET) occlusion in subtotal petrosectomy relative to the occlusive material used and to the varying protympanum anatomy, by means of standardized alignment of the cochlea-carotid artery relation on computed tomography images.

Patients and methods: All cases of subtotal petrosectomy carried out by the same surgeon at a tertiary care referral center were retrospectively evaluated. Only cases with available computed tomography prior to second stage cochlear or middle ear implantation were included. The occlusive material was either muscle tissue or oxidized regenerated cellulose in combination with bone wax. On 3D multiplanar image reconstruction, the varying topographic interrelation of the cochlea and the petrous carotid artery was measured and categorized into two groups: detachment or overlapping.

Results: In 9 (31%) of the 29 included cases there was insufficient occlusion of the ET. In none of these cases was an infection of the fat filling in the obliterated cavity observed during the implantation procedure on second stage (average 10 months interval). The failure rate of both occlusion materials was almost the same (using muscle tissue, in 4 (33.3%) of 12 or oxidized regenerated cellulose, in 5 (29.4%) of 17 cases). It was also similar for both materials in each of the anatomic variation groups.

Conclusions: An incomplete occlusion of the ET alone does not appear to lead to an infection of the obliterated cavity. Autologous muscle tissue and oxidized regenerated cellulose had similar rates of ET occlusion failure. The topographical variance of the protympanum appears to have no direct influence on the success of the ET occlusion.

KEYWORDS

carotid canal, eustachian tube, obliteration, occlusion, protympanum, subtotal petrosectomy

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

© 2020 The Authors. *Laryngoscope Investigative Otolaryngology* published by Wiley Periodicals LLC on behalf of The Triological Society.

1 | INTRODUCTION

Subtotal petrosectomy is a well-established surgical procedure that enables hearing restoration by means of cochlear implants and active middle ear implants in challenging cases with chronic and recurrent otitis media. The revision rate after subtotal petrosectomy caused by infection of the fat filling of the obliterated cavity varies widely in the literature from 0% to 16% of the operated cases.¹ Besides closure of the external auditory canal and complete removal of the infected mucosa, occlusion of the tympanic orifice of the eustachian tube (ET) have been thought to prevent fat graft infection.² However, the efficacy and benefit of ET occlusion in subtotal petrosectomy is unknown, so that its role as a source of infection is questionable.

The present study evaluates the success rate of this surgical step using two different occlusive materials. Additionally, it explores whether there is an anatomic predisposition for insufficient ET occlusion in subtotal petrosectomy using objective comparison of varying protympanum anatomy in different patients. For this purpose, a method for standardization of the topographical interrelation between the cochlea and the petrous carotid artery on computed tomography images was developed.

2 | MATERIALS AND METHODS

2.1 | Patients

All cases of subtotal petrosectomy with abdominal fat obliteration of the resulting tympanomastoidal cavity carried out by a single experienced surgeon (senior author) at a tertiary care referral center were retrospectively evaluated. This study was conducted in line with the ethical standards of the institutional review board. All cases had already undergone multiple ear operations due to chronic otitis media with dry radical cavity or active inflammation and were carried out in a 10-year period in preparation for implantation of active middle ear implants (vibrant soundbridge, bone bridge, middle ear transducer, direct acoustic stimulator) or cochlear implant. Only cases with available computed tomography (in all cases cone beam computed tomography) prior to the second stage hearing aid implantation were included.

2.2 | Surgical technique

After creating a common tympanomastoidal cavity all epithelial and inflammatory tissue was meticulously removed, the tympanic orifice of the ET was blocked, the external auditory canal was closed in blind sac, and the compartmentalized cavity was obliterated with abdominal fat.

2.3 | Data acquisition

Temporal bone cone beam computed tomography data was performed on a stationary Xoran MiniCAT (Ann Arbor, Michigan)

equipped with a 536 × 536 matrix detector resulting in 0.3 mm³ isotropic voxel (standard department protocol: 125 kVp, 7 mA).

The success of ET occlusion was determined according to the aeration of the obliterated cleft on computed tomography and was correlated to the material for occlusion and the topography of the protympanum.

2.4 | Occlusive material

The material used for ET occlusion was either temporalis muscle tissue (n = 12) or oxidized regenerated cellulose (Surgicel, Ethicon, Somerville, NJ, n = 17), both supported by bone wax.

2.5 | Protympanum anatomy

The cochlea-carotid artery relation, which determines the form of the protympanum and of the tympanic orifice of the ET was assessed (Figure 1). DICOM data processing was performed with imaging software Osirix MD (Pixmeo, Los Angeles, California). Evaluation and measurements were performed in standardized alignment using three-dimensional multiplanar reconstruction which provides three windows, for the three main orthogonal planes (Figure 2). The reference plane (bottom left window, violet) was set through the maximal length of the basal cochlear turn and then in a second section (top right window, blue) it was readjusted as a line through the upper edge of the round window running directly under the modiolus. The third plane (top left window, orange) was determined from the first two. Finally, the interrelation between the basal turn of the cochlea and the bony carotid canal was categorized as detachment or overlapping of both structures and the interval was measured parallel to the blue plane (Figure 3). Our objective was not to determine the minimum distance between these varying structures, but to set a standard alignment for further analysis and comparable measurements.

3 | RESULTS

11 (15.3%) of the 72 reviewed cases underwent revision surgery because of dehiscence of the wound closure retroarticular or in the ear canal. At the time of data acquisition, 9 (12.5%) had not received an implant and 3 (4.2%) were simultaneously implanted. All 29 patients who met the above-mentioned inclusion criteria were adult (17 female, 12 male, average age 61 years, range 27 to 81 years). The interval between the evaluated second stage implantation procedure to the initial subtotal petrosectomy ranged from 4 to 28 months (average 10 months). In 9 (31%) of the cases there was insufficient occlusion of the ET, with air in the obliterated cavity to varying extent (Figure 4). In none of these cases was an infection of the fat graft observed. There were also no signs of foreign body reaction caused by Surgical or bone wax.

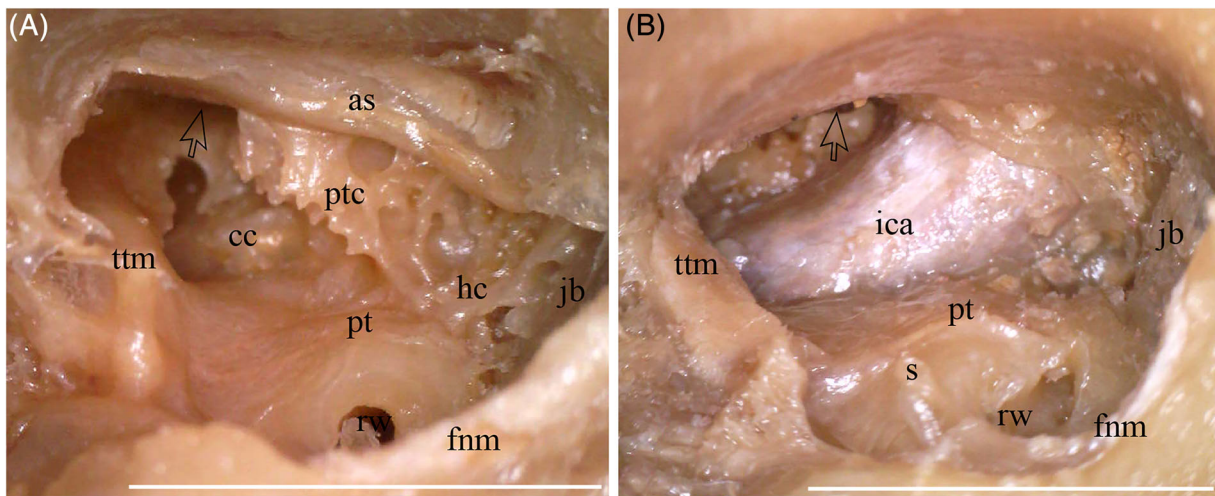


FIGURE 1 Dissected temporal bone specimens. Intact protympanum demonstrated from surgical point of view during subtotal petrosectomy, A, and situs after removal of the peritubal cells (ptc) and hypotympanal cells (hc), B. Arrow indicates the ostium of the osseous ET. as, annular sulcus; cc, carotid canal; fnm, mastoidal segment of facial nerve; ica, skeletonized ascending petrous internal carotid artery; jb, jugular bulb; pr, promontory of the cochlea; rw, round window niche; s, stapes; ttm, tensor tympani muscle. Scale bar: 1 cm

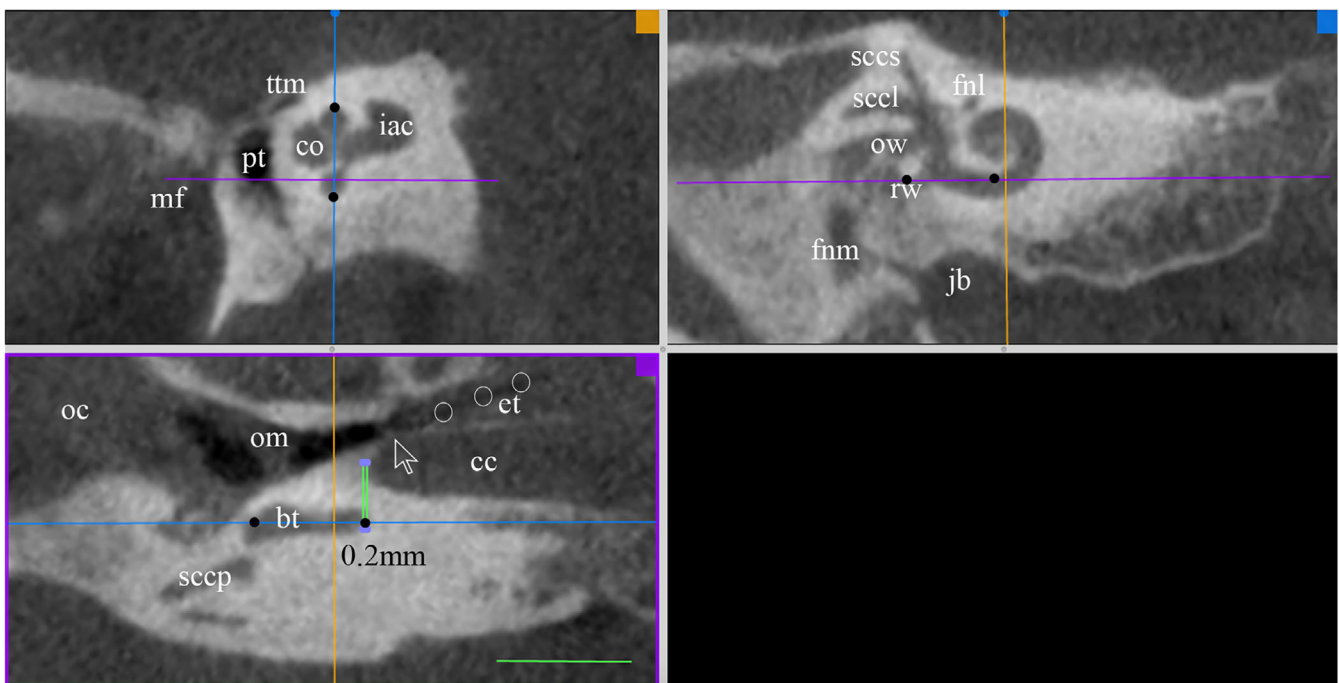


FIGURE 2 Screenshot of the Osirix MD workstation for three-dimensional multiplanar reconstruction. Standard alignment of cone beam computed tomography dataset for measuring the varying interrelation between the basal turn of the cochlea (co/bt) and the carotid canal (cc) in a right temporal bone. In this case slight detachment (0.2 mm) is shown. The relation between both landmarks was measured parallel to the standardized blue line on the green rectangle. Black dots, standard alignment points; arrow, tiny bony plate covering the intrapetrous bend of the carotid canal; white circles, eustachian tube course; jb, jugular bulb; ttm, tensor tympani muscle; oc, obliterated cavity; om, occlusion material; mf, mandibular fossa; facial nerve segment, labyrinthine (fnl) and mastoid (fnm); pt, protympanum; iac, internal auditory canal; rw, round window; ow, oval window; semicircular canal, superior (sccs), lateral (sccl), and inferior (scci). Scale bar: 1 cm

The failure rate of both occlusion materials was similar (using muscle tissue, in 4 (33.3%) of 12 or oxidized regenerated cellulose, in 5 (29.4%) of 17 cases, Figure 4). The topographical interrelation of the above-mentioned landmarks varied from overlapping (average

1.3 mm, range 0.2 to 3.1 mm) to detachment (average 1.5 mm, range 0.1 to 5.3 mm). Insufficient ET occlusion could be seen in 4 (28.6%) of all 14 cases with overlapping (with muscle, 3 (33.3%) of 9 or with Surgicel, 1 (20%) of 5 cases) and in 5 (33.3%) of all 15 cases with

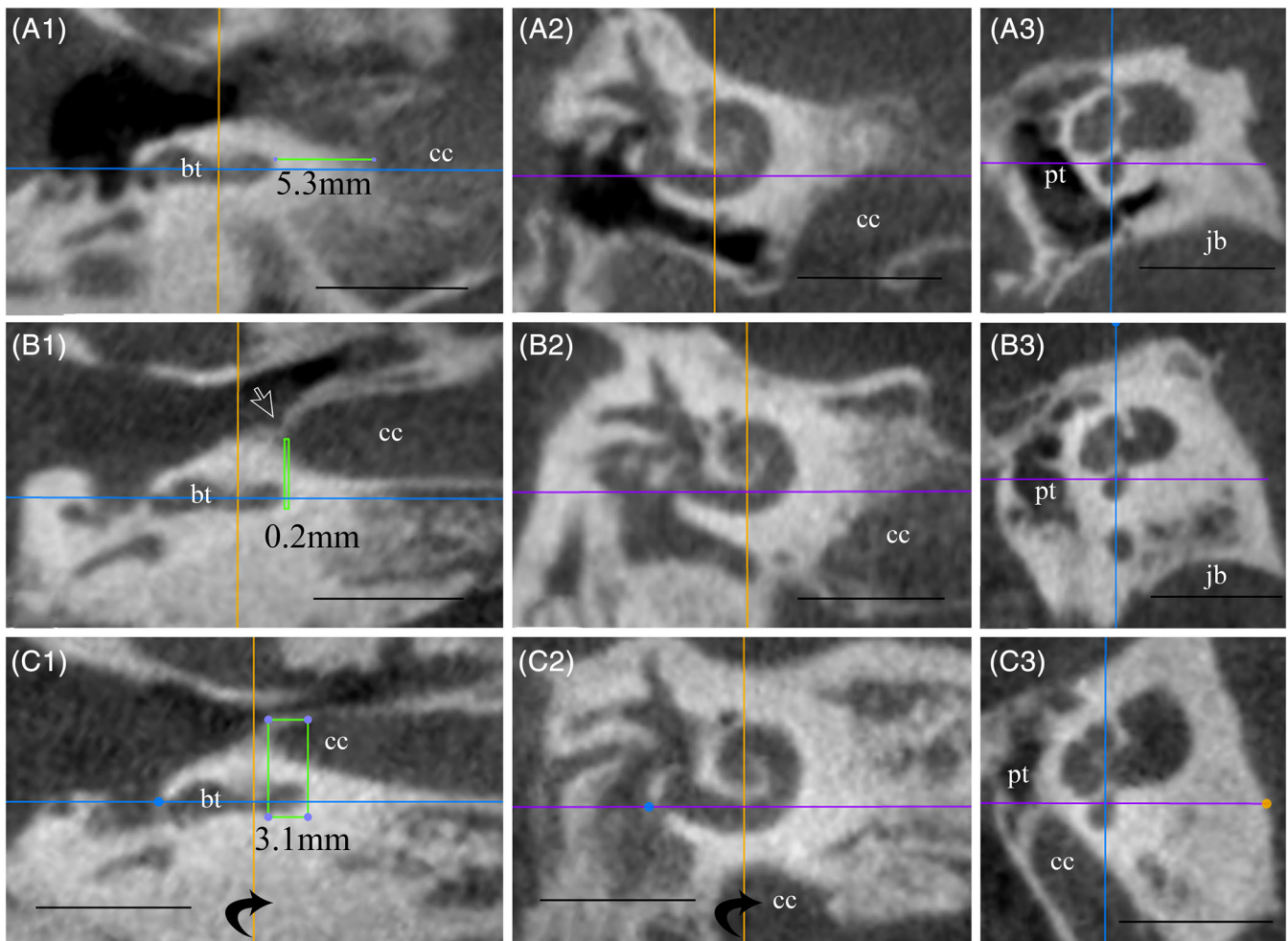


FIGURE 3 Comparison of three representative cases in the standardized main orthogonal planes. A, Right ear, maximal detachment (interval: 5.3 mm), occlusion with Surgicel and bone wax, 4 months after subtotal petrosectomy. Despite occlusive material in the tympanic orifice there are some residual cells between the basal turn of the cochlea and the carotid canal (not displayed in the standard planes) leading to insufficient ET occlusion with extensive aeration of the tympanic cleft. No clinical signs and no infection in second stage surgery were detected. B, Right ear, slight overlapping (interval: 0.2 mm), sufficient ET occlusion with muscle fragments and bone wax, 8 months after subtotal petrosectomy. Arrow shows an iatrogenic thinning of the carotid wall. C, Left ear, maximal overlapping (3.1 mm), ET occlusion with muscle fragments and bone wax, 7 months after subtotal petrosectomy. Blue and violet planes are mirrored for better visual comparison of the left ear with the right ones (turn arrows on C1 and C2), the mid-modiolar plane (C3) remains the same. The carotid artery bulges into the protympanum. Notice in the orange plane how the form of the protympanum is determined from both major structures: the cochlea and the carotid canal (A3, B3, and C3). Green line and rectangle, measuring tools for determining the distance by which the two landmarks overlap or detach parallel to the standardized blue line. Scale bar: 1 cm

detachment (irrespective of the occlusive material 33.3%; with muscle, 1 of 3 or with Surgicel, 4 of 12 cases).

To minimize the influence of the anatomic variable 16 of the 29 cases could be matched in 8 pairs of different material but similar cochlea-carotid artery relation distance, 5 in the overlapping and 3 in the detachment category. In all but one of all these pairs the same occlusion result was achieved (Figure 4).

4 | DISCUSSION

This study evaluates influential factors for insufficient ET occlusion in subtotal petrosectomy with the intention to weigh benefit against

potential risk of this surgical step. There are many reasons for postoperative infection of the fat graft, the main one undoubtedly being residual infected mucosa in bony cells.³ Since all the included cases in the current study were infection free during the second stage implantation, their evaluation could retrospectively give some insight into the role of ET occlusion alone in prevention of infection.

In the first aspect of the study, two occlusion materials were compared. These vary in the literature from different autologous soft tissues to inert materials as well as combinations of both: periosteum, free temporalis muscle graft with fascia⁴ or in combination with connective tissue,⁵ folded back tensor tympani muscle,⁶ small cartilage fragments from the outer ear canal,⁷ bone pate,⁸ bioactive ionomeric cement,⁹ incus with inverting of the mucosa,¹⁰ hydroxyapatite

the ET (Figure 3C). In such cases the tiny carotid wall is the medial wall of the osseous path to the ET isthmus. After subtotal petrosectomy in typical surgical view along the promontory, the proximal carotid artery close to the annular sulcus is higher than the distal vertical segment (Figure 1B). This anatomical feature should be kept in mind since the anterior hypotympanic cells and the peritubal cells lay over the carotid canal. By drilling in such a narrow blind ending on a bone-to-soft tissue interface, the diamond burr can easily flip into the carotid canal.

In the literature, the incidence of carotid canal dehiscence in human temporal bones ranges widely from 4.9% to 35.2%.^{18,19} Moreano and colleagues who examined the largest number of serial sectioned temporal bones found 7.7% with dehiscence, additionally 7.4% with a microdehiscence and 15.5% with a wafer-thin carotid canal wall in 1000 specimens.²⁰ Furthermore, Savic and Djeric reported in 150 specimens 22.2% with a wafer-thin carotid canal wall, and which in 2% was even missing.²¹ The maximal bone thickness which separated the ET from the internal carotid artery was 3 mm.

Pauna and colleagues found on serial histological sections an increased incidence of carotid canal dehiscence in temporal bones of deceased donors with chronic otitis media compared to a control group.²² The dehiscence, which was frequently closer to the promontory, was larger in size and the bony wall (when present) was thinner compared to findings in non-diseased ears. On the other hand, in cases with active chronic otitis media the mucosa is usually scarred, hyperplastic and vulnerable with good blood supply so that its removal is performed under a suboptimal operative view. Injuring the caroticotympanic artery from the carotid canal additionally can worsen the orientation in the surgical field.

The petrous carotid artery has a thin vein-like wall, which lacks muscle and elastic fibers and does not pulsate.²³ Moreover, in aged patients the wall of the internal carotid artery is often atherosclerotic, dilated and thinned, so that the bony carotid canal stabilizes its lumen. Sometimes it can even be totally atrophied and the bony canal replaces the artery wall, meaning that if the bony scaffold is opened, the artery could be easily injured.²⁴ However, since in 96% of temporal bones the carotid artery forms a barrier between the air spaces anterior and posterior, particular attention to the carotid artery is warranted to achieve successful ET occlusion.²⁵

Ugo Fisch, the name giver of "subtotal petrosectomy," recommended that the internal carotid artery should be followed with diamond burr in order to remove the bony ET as far as the isthmus.²⁶ After the mucosa is coagulated the obliteration should be done "with bone wax, which is firmly packed with a suction tip covered with a neurosurgical cottonoid." However, he described this technique primarily as an approach to the lateral skull base and not as an eradication procedure for chronic otitis media.

Taking all facts mentioned above into consideration, as well as the fact that most of the patients undergoing subtotal petrosectomy in preparation for hearing implants have a clinical history of multiple curative surgeries for chronic otitis media, there is an increased risk of injuring or plugging the carotid artery in its dehiscent or iatrogenic weakened bony canal by pushing the occluding material firmly into a

funnel like ET orifice. Therefore, the surgeon should consider how much risk is reasonable to take for sufficient occlusion. In the presented case series, after the mucosa of the protympanum was removed with diamond drill without opening the carotid canal, the occlusive material was pushed gently into the tympanic orifice.

It should also be considered that sequelae from iatrogenic trauma of the artery wall could remain unrecognized. Vascular stenosis of the carotid artery through atheromatous plaques is not rare in aged individuals. Furthermore, soft and vulnerable plaques in the petrous segment are a diagnostic challenge and could remain invisible in preoperative magnetic resonance imaging workup without special sequences.²⁷ Consequently, manipulation of the carotid artery wall could potentially lead in such cases to plaque rupture and in the long-term to clinically relevant arterial stenosis, which would not be directly connected to the operation.

Knowledge of the exact location of the carotid canal can minimize the risk of accidental injury to the internal carotid artery and would assist the surgeon to drill more safely in this region. Detailed preoperative assessment of the individual anatomy of the patient with computed tomography scans is easily facilitated by using three-dimensional multiplanar reconstruction as shown in Figure 2.

An interesting alternative for traditional transtympanic ET closure is endonasal ablation for which various surgical techniques have already been described in the literature.²⁸ Almost all these were developed to address recalcitrant cerebrospinal fluid rhinorrhea after skull base surgery and none describe a problem of simultaneous infection of the fat graft with insufficient ET occlusion. Barañano and colleagues used such a technique in a case of subtotal petrosectomy for chronic otitis media with aeration of the obliterated cavity 8 months after surgery in which they successfully closed the ET transnasally by ablation using fat tissue from the ear lobe in monitored anesthesia care.²⁹ Unfortunately, they did not explain why they decided to perform revision of this "noninfectious complication" 8 months after the initial obliterative surgery.

Finally, a prospective study should assess whether transtympanic ET occlusion after subtotal petrosectomy for eradication of chronic otitis media has any role in the prevention of fat graft infection in the obliterated cavity. The findings of such a study could make it easier for ear surgeons to decide how far they should proceed drilling into the protympanum to achieve successful ET occlusion and whether this surgical step is even necessary.

5 | CONCLUSION

In our study, an incomplete occlusion of the eustachian tube after subtotal petrosectomy does not appear to lead to an infection of the obliterated cavity. Autologous tissue, such as temporalis muscle, may be considered to be just as suitable for tube occlusion as an inert material like oxidized regenerated cellulose. The topographical variance of the protympanum seems to have no direct influence on the success of ET occlusion.

ACKNOWLEDGMENT

Human temporal bones were acquired from autopsies of elderly subjects in line with the donation program of the institution. The authors acknowledge the contribution made by the donors of the tissue. We would like to thank Mr. P. James for proofreading of the manuscript.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ORCID

Stefan Lyutenski  <https://orcid.org/0000-0002-6399-2081>

REFERENCES

- Prasad SC, Roustan V, Piras G, Caruso A, Lauda L, Sanna M. Subtotal petrosectomy: surgical technique, indications, outcomes, and comprehensive review of literature. *Laryngoscope*. 2017;127:2833-2842.
- Free RH, Falcioni M, Di Trapani G, Giannuzzi AL, Russo A, Sanna M. The role of subtotal petrosectomy in cochlear implant surgery—a report of 32 cases and review on indications. *Otol Neurotol*. 2013;34:1033-1040.
- Lyutenski S, Schwab B, Lenarz T, Salcher R, Majdani O. Impact of the surgical wound closure technique on the revision surgery rate after subtotal petrosectomy. *Eur Arch Otorhinolaryngol*. 2016;273:3641-3646.
- Issing PR, Schonemark MP, Winkelmann S, Kempf HG, Ernst A. Cochlear implantation in patients with chronic otitis: indications for subtotal petrosectomy and obliteration of the middle ear. *Skull Base Surg*. 1998;8:127-131.
- Bernardeschi D, Nguyen Y, Smail M, et al. Middle ear and mastoid obliteration for cochlear implant in adults: indications and anatomical results. *Otol Neurotol*. 2015;36:604-609.
- Leung R, Briggs RJ. Indications for and outcomes of mastoid obliteration in cochlear implantation. *Otol Neurotol*. 2007;28:330-334.
- Schuknecht HF, Chandler JR. Surgical obliteration of the tympanomastoid compartment and external auditory canal. *Ann Otol Rhinol Laryngol*. 1984;93:641-645.
- Coker NJ, Jenkins HA, Fisch U. Obliteration of the middle ear and mastoid cleft in subtotal petrosectomy: indications, technique, and results. *Ann Otol Rhinol Laryngol*. 1986;95:5-11.
- Ensink RJ, Vingerhoets HM, Schmidt CW, Cremers CW. Treatment for severe palatoctonus by occlusion of the eustachian tube. *Otol Neurotol*. 2003;24:714-716.
- Samii M, Draf W. *Surgery of the Skull Base: An Interdisciplinary Approach*. Heidelberg: Springer Verlag; 1989.
- Kveton JF. Obliteration of the eustachian tube using hydroxyapatite cement: a permanent technique. *Laryngoscope*. 1996;106:1241-1243.
- Verhaert N, Mojallal H, Schwab B. Indications and outcome of subtotal petrosectomy for active middle ear implants. *Eur Arch Otorhinolaryngol*. 2013;270:1243-1248.
- Van Osch K, You P, Zimmerman K, Yoo J, Agrawal SK. Chronic inflammatory reaction to bone wax in cochlear implantation: a case report and literature review. *Cochlear Implants Int*. 2020;21(5):295-298.
- Zhou H, Ge J, Bai Y, Liang C, Yang L. Translation of bone wax and its substitutes: history, clinical status and future directions. *J Orthop Translat*. 2019;17:64-72.
- Linthicum FH Jr. The fate of mastoid obliteration tissue: a histopathological study. *Laryngoscope*. 2002;112:1777-1781.
- Jen A, Sanelli PC, Banthia V, Victor JD, Selesnick SH. Relationship of petrous temporal bone pneumatization to the eustachian tube lumen. *Laryngoscope*. 2004;114:656-660.
- Saim L, McKenna MJ, Nadol JB Jr. Tubal and tympanic openings of the peritubal cells: implications for cerebrospinal fluid otorhinorrhea. *Am J Otol*. 1996;17:335-339.
- Penido Nde O, Borin A, Fukuda Y, Lion CN. Microscopic anatomy of the carotid canal and its relations with cochlea and middle ear. *Braz J Otorhinolaryngol*. 2005;71:410-414.
- Hasebe S, Sando I, Orita Y. Proximity of carotid canal wall to tympanic membrane: a human temporal bone study. *Laryngoscope*. 2003;113:802-807.
- Moreano EH, Paparella MM, Zelterman D, Goycoolea MV. Prevalence of carotid canal dehiscence in the human middle ear: a report of 1000 temporal bones. *Laryngoscope*. 1994;104:612-618.
- Savic D, Djerić D. Anatomical variations and relations in the medial wall of the bony portion of the eustachian tube. *Acta Otolaryngol*. 1985;99:551-556.
- Pauna HF, Monsanto RC, Schachern PA, et al. The surgical challenge of carotid artery and fallopian canal dehiscence in chronic ear disease: a pitfall for endoscopic approach. *Clin Otolaryngol*. 2017;42:268-274.
- Nevoux J, Loundon N, Leboulanger N, Roger G, Ducou Le pointe H, Garabedian EN. Cochlear implant in the carotid canal. Case report and literature review. *Int J Pediatr Otorhinolaryngol*. 2010;74:701-703.
- Schuknecht HF, Gulya AJ. *Anatomy of the Temporal Bone with Surgical Implications*. Philadelphia: Lea & Febiger; 1986.
- McKay-Davies I, Selvarajah K, Neeff M, Sillars H. The importance of petrous apex and peri-carotid pneumatization in subtotal petrosectomy and blind sac closure: a radiological study. *J Laryngol Otol*. 2018;132:698-702.
- Fisch U, Mattox D. *Microsurgery of the Skull Base*. Stuttgart: Georg Thieme Verlag; 1988.
- Hayashi K, Seyama H, Yamada net al. The stenting to internal carotid artery stenosis (ICS) in petrous portion. The evaluation of plaque figures in magnetic resonance image. *Interv Neuroradiol*. 2006;12:193-196.
- Lucke-Wold B, Brown EC, Cetas JS, et al. Minimally invasive endoscopic repair of refractory lateral skull base cerebrospinal fluid rhinorrhea: case report and review of the literature. *Neurosurg Focus*. 2018;44:E8.
- Baranano CF, Kopelovich JC, Dunn CC, Gantz BJ, Hansen MR. Subtotal petrosectomy and mastoid obliteration in adult and pediatric cochlear implant recipients. *Otol Neurotol*. 2013;34:1656-1659.

How to cite this article: Lyutenski S, El-Saied S, Schwab B. Impact of occlusive material and cochlea-carotid artery relation on eustachian tube occlusion in subtotal petrosectomy. *Laryngoscope Investigative Otolaryngology*. 2020;5:1140-1146. <https://doi.org/10.1002/lio2.478>