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Comparison of Transmastoid and Middle Fossa Approaches for Superior Canal Dehiscence Repair: A Multi-institutional Study

Seth R. Schwartz, MD, MPH[1], Galit Almosnino, MD[1], Kathryn Y. Noonan, MD[2], Renee M. Banakis Hartl, MD, AuD[3], Daniel M. Zeitler, MD[1], James E. Saunders, MD, MS[2], and Stephen P. Cass, MD, MPH[3]

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Abstract

Objective. To compare outcomes for patients undergoing a transmastoid approach versus a middle fossa craniotomy approach with plugging and/or resurfacing for repair of superior semicircular canal dehiscence. Outcome measures include symptom resolution, hearing, operative time, hospital stay, complications, and revision rates.

Study Design. Multicenter retrospective comparative cohort study.

Settings. Three tertiary neurotology centers.

Subjects and Methods. All adult patients undergoing repair for superior canal dehiscence between 2006 and 2017 at 3 neurotology centers were included. Demographics and otologic history collected by chart review. Imaging, audiometric data, and vestibular evoked myogenic potential measurements were also collected for analysis.

Results. A total of 68 patients (74 ears) were included in the study. Twenty-one patients underwent middle fossa craniotomy repair (mean age, 47.9 years), and 47 underwent transmastoid repair (mean age, 48.0 years). There were no significant differences in age or sex distribution between the groups. The transmastoid group experienced a significantly shorter duration of hospitalization and lower recurrence rate as compared with the middle fossa craniotomy group (3.8% vs 33%). Both groups experienced improvement in noise-induced vertigo, autophony, pulsatile tinnitus, and nonspecific vertigo. There was no significant difference among symptom resolution between groups. Additionally, there was no significant difference in audiometric outcomes between the groups.

Conclusion. Both the transmastoid approach and the middle fossa craniotomy approach for repair of superior canal dehiscence offer symptom resolution with minimal risk. The transmastoid approach was associated with shorter hospital stays and lower recurrence rate as compared with the middle fossa craniotomy approach.

Keywords

superior canal dehiscence, transmastoid, middle fossa craniotomy, clinical outcomes, Tullio

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Superior canal dehiscence syndrome (SCDS) involves auditory and vestibular symptoms caused by an abnormal opening in the bone overlying the superior semicircular canal, resulting in a third mobile window into the inner ear.[1] The dehiscence allows for dissipation of acoustic energy and aberrant stimulation of the vestibular system by sound and pressure passage through the extra window.[2-4] The consequent symptoms can be debilitating for patients. These symptoms of sound- or pressure-induced vertigo, hyperacusis, autophony, and hearing loss characterize the disease.

The diagnosis of superior canal dehiscence (SCD) relies on clinical presentation and is confirmed with high-resolution computed tomography and abnormal vestibular evoked myogenic potential (VEMP) testing. There may be conductive hearing loss with supranormal bone thresholds.[4-6]

[1]Section of Otology/Neurotology, Department of Otolaryngology–Head and Neck Surgery, Virginia Mason Medical Center, Seattle, Washington, USA
[2]Division of Otolaryngology, Dartmouth Hitchcock Medical Center, Geisel School of Medicine at Dartmouth, Lebanon, New Hampshire, USA
[3]Department of Otolaryngology, School of Medicine, University of Colorado, Aurora, Colorado, USA

Corresponding Author:
Seth R. Schwartz, MD, MPH, Department of Otolaryngology–Head and Neck Surgery, Virginia Mason Medical Center, 1100 Ninth Avenue, Mailstop X10-ON, Seattle, WA 98101, USA.
Email: Seth.schwartz@virginiamason.org

For those patients with severe symptoms, surgical repair can significantly improve symptoms. Surgery can involve simple resurfacing of the dehiscent canal, plugging the canal, or both. SCD repair was originally performed through a middle fossa craniotomy approach (MFCA).[7-9] More recently, the transmastoid approach (TMA) has gained popularity as a safe alternative with comparable outcomes and symptom resolution.[10] While both approaches offer symptom resolution, the MFCA involves risks of a craniotomy and brain retraction. The TMA does not allow direct visualization of the dehiscence but offers a less invasive approach without the morbidity of a craniotomy.

Various studies describe the MFCA and TMA for repair. There is no consensus regarding the favored approach. Furthermore, no studies directly compare the 2 approaches. The purpose of this study is to compare subjective and objective outcomes—including symptom resolution, audiometric outcomes, complications, and revision rates—between patients undergoing SCD repair via an MFCA and a TMA.

Methods

This was a multicenter retrospective comparative study of adult patients undergoing surgical repair for SCD by TMA or MFCA at 3 tertiary care neurotology programs between 2006 and 2017 (Virginia Mason Medical Center, Dartmouth University, University of Colorado). This study was approved by all participating institutions (VMMC IRB 16108). Demographic information and otologic history (head trauma, barotrauma, middle ear disease, prior surgery) were collected through chart review. Presenting symptoms, imaging, audiometric data, and VEMP measurements were also analyzed. At 2 institutions, pre- and postoperative records were reviewed for symptom resolution. At the third institution, a questionnaire with a numeric rating system (0-5) was used.

Diagnosis of SCD was made by symptoms and imaging and was often confirmed by abnormal cervical VEMP testing (decreased thresholds on the affected sides). High-resolution computed tomography scans of the temporal bone confirmed a bony dehiscence overlying the superior semicircular canal. All computed tomography scans had thin slices (0.6 mm) and were reformatted to the plane of the superior canal, including views parallel to (Poschl) and orthogonal to (Stenver) the superior semicircular canal. A number of patients had incomplete audiometric data. For analysis, these patients were excluded from audiometric analysis. Fourteen of 21 patients (67%) in the MFCA group and 39 of 53 (74%) in the TMA group had complete audiometric data. Hearing data were compiled in a scattergram with the standardized format for reporting hearing outcomes.[11] Pure tone average (PTA) was calculated according to the 2012 guidelines of the American Academy of Otolaryngology—Head and Neck Surgery with 500, 1000, 2000, and 3000 Hz. PTA was also calculated with 500, 1000, 2000, and 4000 Hz for air conduction (AC) and bone conduction (BC).

Statistics

Patient data were collected in Microsoft Excel. Statistical analysis was performed with Microsoft Excel and SPSS software (version 21; IBM, Chicago, Illinois). Descriptive statistics were used for patient demographics, VEMP testing, and clinical outcomes, including symptom resolution, revisions, and complications. For audiometric data, paired t tests were used to compare same-subject data, and unpaired t tests were used to compare group means. For symptoms, Fischer's exact test was used to compare symptom resolution between groups. P values $<.05$ were considered statistically significant.

Surgical Technique

Transmastoid Approach. The TMA was performed similarly among the 3 institutions. Through a postauricular incision, a cortical mastoidectomy is performed. The lateral semicircular is skeletonized and the tegmen thinned to expose the superior canal.

With plugging, the superior semicircular canal is blue-lined proximal and distal to the dehiscent region. Small fenestrations are created at both ends of the canal, avoiding the ampulla and the common crus. Mechanical and/or suction trauma of the membranous labyrinth is avoided. Bone dust is mixed with fibrin sealant to create bone pâté, which is used to plug the canal. The plugged fenestrations are covered with bone pâté and sealed with temporalis fascia and fibrin sealant.

When resurfacing is done alone or in addition to plugging, the middle fossa dura is elevated from the tegmen overlying the dehiscent superior canal. In most cases, a piece of fascia is inserted between the superior canal dome and the dura. A conchal cartilage graft is placed between the fascia and dura in an intracranial, extradural position to entirely cover the superior canal dome.

Middle Fossa Craniotomy Approach. A standard middle fossa craniotomy is performed, and the dura is elevated off the middle fossa floor. The geniculate ganglion and greater superficial petrosal nerve are identified. The dehiscent superior semicircular canal is identified, and the overlying dura is elevated. The anterior and posterior limbs of the dehiscent segment are packed with bone pâté. The canal is resurfaced with bone pâté and fibrin glue. A segment of the cranial bone flap is placed extradurally, overlying the repaired superior canal and any areas of the tegmen that are dehiscent. Additional bone pâté is packed around the bone graft, and fibrin sealant is used to seal it into position. Duraform is placed between the dura and bone graft, and the craniotomy is closed with titanium mesh.

Results

Seventy-five patients who underwent surgical repair of SCD were identified through chart review per the *CPD* code for SCD repair (69960; *Current Procedural Terminology*) and the *ICD-9* and *ICD-10* codes for Tullio phenomenon and

Table 1. Patient Demographics and Preoperative Symptoms.

Group	Mean Age, y	Sex, n (%)		Side, n		Symptom, %				
		Female	Male	Left	Right	Aural Fullness	Vertigo	Autophony	Tullio	Pulsatile Tinnitus
MFCA (n = 21)	47.9	14 (67)	7 (33)	9	12	28.5	42.9	57	61.9	33.3
TMA (n = 53)	48	25 (53)	22 (47)	37	16	37.7	62.3	77.4	41.5	50.9

Abbreviations: MFCA, middle fossa craniotomy approach; TMA, transmastoid approach.

Table 2. Repair Technique in the MFC and TSM Groups.[a]

Group	Plug	Resurface	Combination
MFCA (n = 21)	28.6	4.8	66.7
TMA (n = 53)	45.3	20.7	34

Abbreviations: MFCA, middle fossa craniotomy approach; TMA, transmastoid approach.
[a]Values are presented as percentages.

autophony (*International Classification of Diseases*). Seven patients were excluded due to a history of middle ear disease. The remaining 68 patients (74 ears) were included (29 men, 39 women). Twenty-one patients (21 ears) underwent MFCA repair, and 47 (53 ears) underwent TMA repair. Of the 53 patients in the TMA group, 6 had bilateral repairs. There were no significant differences between groups in age or sex (**Table 1**). Preoperative symptoms were reported, including aural fullness, vertigo, autophony, Tullio phenomenon, and tinnitus. The majority of patients in both groups underwent plugging with or without resurfacing (**Table 2**). Duration of hospitalization was significantly shorter for the TMA cohort versus the MFCA cohort (29.7 vs 43.1 hours). There was no significant difference in mean operative time (MFCA, 2.01 hours; TMA, 1.49 hours). The mean follow-up time was 12.1 months.

All patients had preoperative high-resolution computed tomography of the temporal bone, and all had radiographic dehiscence. Cervical VEMP thresholds were available for 68 of 74 ears (92%), 67 (99%) of which had decreased thresholds on the affected side. VEMPs were not routinely measured postoperatively; therefore, pre- to postoperative comparisons were not performed.

Audiometric Outcomes

All patients had preoperative audiometric testing (**Figures 1-4**). There was no significant difference in mean preoperative air-bone gap (ABG) between the MFCA group (9.0 dB) and TMA group (12.5 dB) or in mean preoperative AC PTA between the MFCA group (17.6 dB) and the TMA group (22.9 dB). There was no significant change in pre- to postoperative mean ABG in either group (9.0 to 7.8 dB in the MFCA group, 12.5 to 12.3 dB in the TMA group). Additionally, there was no significant difference in ABG change score between the groups. Only 5 of 74 patients

Word Recognition Score (%)

Pure Tone Average (dB)	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	> 91
0-10										1
11-20										9
21-30										4
31-40										
41-50										
51-60										
61-70										
71-80										
81-90										
≥ 91										

Figure 1. Preoperative hearing: middle fossa craniotomy approach group.

Word Recognition Score (%)

Pure Tone Average (dB)	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	> 91
0-10										3
11-20										21
21-30										0
31-40									1	2
41-50										1
51-60										1
61-70										1
71-80										
81-90										
≥ 91										

Figure 2. Preoperative hearing: transmastoid approach group.

Word Recognition Score (%)

Pure Tone Average (dB)		Improved						Worse				
		≥50	40	30	20	10	No Change	10	20	30	40	50
Improved	≥50											
	40											
	30											
	20											
	10						1					
	No Change						12					
	10						1					
	20											
Worse	30											
	40											
	≥50											

Figure 3. Postoperative hearing: middle fossa craniotomy approach group

Pure Tone Average (dB)		Word Recognition Score (%): Improved ≥50	40	30	20	10	No Change	Worse 10	20	30	40	50
Improved	≥50											
	40											
	30											
	20											
	10					1						
	No Change					1	33	2				
Worse	10						1					
	20											
	30						1					
	40											
	≥50											

Figure 4. Postoperative hearing: transmastoid approach group.

Table 3. ABG Scores of Patients with Preoperative ABG >10 dB.

Approach	Patients, n (%)	Mean ABG, dB Preoperative	Postoperative	*P* Value
MFCA	6 (43)	15.8	10	.175
TMA	23 (59)	17.2	15.7	.144

Abbreviations: ABG, air-bone gap; MFCA, middle fossa craniotomy approach; TMA, transmastoid approach.

Table 4. Air-Bone Gap by Frequency.[a]

Frequency	MFCA	TMA
500 Hz		
Preoperative	13.6	19.6
Postoperative	7.9	15.1
P value	.079	.131
1000 Hz		
Preoperative	13.6	14.7
Postoperative	8.6	15.8
P value	.121	.636
2000 Hz		
Preoperative	4.29	4.23
Postoperative	2.86	3.97
P value	.414	.841
4000 Hz		
Preoperative	7.5	11.2
Postoperative	11.42	11.5
P value	.151	.861

Abbreviations: MFCA, middle fossa craniotomy approach; TMA, transmastoid approach.
[a]Values are presented as mean dB.

(6.8%) experienced a closure of their preoperative ABG by ≥10 dB: 3 in the TMA group and 2 in the MFCA group.

Table 5. Postoperative Symptom Resolution.

Symptom	Resolved, n (%) MFCA	TMA	*P* Value
Vertigo	4 of 6 (66)	18 of 29 (62)	.85
Autophony	8 of 10 (80)	38 of 40 (95)	.30
Tullio	8 of 10 (80)	17 of 19 (89)	.54
Aural fullness	4 of 5 (80)	11 of 17 (65)	.53
Pulsatile tinnitus	3 of 5 (60)	19 of 24 (79)	.49

Abbreviations: MFCA, middle fossa craniotomy approach; TMA, transmastoid approach.

Low-frequency PTA (250, 500, 1000, and 2000 Hz) was compared for the subset of patients for whom these data were available. Low-frequency ABG decreased from 15.9 to 8.6 dB in the MFCA group (P = .013). The change in low-frequency ABG in the TMA group was not significant (16.1 to 12.6 dB).

To understand the clinical significance of the audiometric outcomes, patients with a preoperative ABG >10 dB were evaluated separately. There was no significant ABG closure in this subset of patients in either group (**Table 3**).

The ABG was analyzed by frequency (500, 1000, 2000, 4000 Hz). There was no significant difference between pre- and postoperative ABG at any frequency, in either group (**Table 4**). Neither group experienced a significant change in AC threshold at any frequency.

Pre- to postoperative absolute changes in BC PTA were calculated. Two patients in the MFCA group and 3 patients in the TMA group experienced an increase in BC by ≥10 dB.

Symptom Resolution

Some data points for subjective postoperative symptom resolution were incomplete. Additionally, presenting symptoms vary by individual; therefore, the denominator for the calculation of symptom resolution varied. Reported results are for those with known outcomes. **Table 5** summarizes the number of subjects in each group who experienced partial or full symptom resolution. **Table 6** breaks this down into full and partial resolution for autophony, Tullio, and unspecified vertigo. There were no significant differences between groups for any symptoms. One patient in the TMA group developed postoperative vertigo while reporting none preoperatively.

Recurrences and Complications

There was a 33.3% revision rate (7 of 21) in the MFCA group (4 of 7 plugging, 3 of 7 plugging and resurfacing). There was a 3.8% revision rate (2 of 53) in the TMA group; both patients had resurfacing only. This difference was statistically significant (P = .0016). Revision surgery was performed on the basis of persistent symptoms.

The complication rate among all patients was 4% (3 of 74). In the MFCA group, 1 patient experienced postoperative facial nerve weakness (House-Brackmann V/VI, which

Table 6. Symptom Resolution Categorized as Complete, None, and Partial for Vertigo, Autophony, and Tullio.[a]

	Vertigo			Autophony			Tullio		
	Complete	None	Partial	Complete	None	Partial	Complete	None	Partial
MFCA	50	33.3	16.6	60	20	20	23.1	15.4	38.5
TMA	55	38	7.0	82.5	5	12.5	63.6	9.0	9.0

Abbreviations: MFCA, middle fossa craniotomy approach; TMA, transmastoid approach.
[a]Values are presented as percentages.

resolved to I/VI). In the TMA group, 1 patient experienced a surgical site infection that resolved with medical treatment. One patient experienced high-frequency sudden sensorineural hearing loss on postoperative day 4 that partially resolved following a course of oral steroids.

Discussion

The surgical management of SCDS and its outcomes are well established. Middle fossa craniotomy and TMA are viable options for treatment of SCDS. While both are invasive and entail significant risk and a potentially prolonged recovery, TMA avoids the morbidity of a craniotomy, has higher patient acceptance, and is more familiar to most otologists.[10,12-15]

Numerous single-institution case series previously documented the successes and risks of each approach.[7-10] Several reviews compared the 2 approaches by assessing these case series.[7,16] Rodgers et al[17] compared patients undergoing MFCA with plugging of the superior canal and a TMA group with resurfacing only (''capping''). The patients with capping alone had a higher rate of residual auditory symptoms, while patients in the MFCA group had fewer residual symptoms. However, this study was more a comparison of plugging and resurfacing than a surgical approach. Furthermore, only 29 patients were included in the cohort, calling the statistical power of the results into question. These results were similar to the current study in that there appears to be a higher failure rate (recurrent symptoms) among patients undergoing a TMA with resurfacing only.

There are currently no studies in the literature that directly compare the 2 surgical approaches with plugging and resurfacing techniques. The purpose of this multicenter study was to directly compare outcomes as well as complication and failure rates between the MFCA and the TMA for the treatment of SCDS.

The middle fossa approach requires a craniotomy to access the superior semicircular canal. This often means that patients are admitted and observed in an intensive care unit setting for at least 1 night, many of whom remain in the hospital for $\geq$24 hours postoperatively. In contrast, there are studies demonstrating the safety of performing the TMA in an outpatient setting.[18] We found a significantly shorter length of hospital stay in the transmastoid group. Due to the retrospective nature of the current study, data regarding actual time to return to work were not evaluated.

Following repair of SCD, success of the operation can be defined by several measures. Symptom resolution is likely the most valuable from the patient's perspective. The current study assessed resolution of the most common symptoms seen in SCDS, including autophony, sound-induced vertigo, vertigo/dizziness, pulsatile tinnitus, and aural fullness.

Autophony (awareness of bodily noises) is often the dominant symptom of patients with SCDS.[19,20] Both surgical approaches offer significant resolution of this symptom. Although there was no significant difference in symptom resolution between the groups, the TMA was associated with a relatively higher rate of resolution of autophony than the MFCA (95% vs 80%) as well as pulsatile tinnitus (79% vs 60%; **Table 5**). The reason for this difference is not entirely clear. It is possible that denser packing of the superior canal through the lateral approach more effectively sealed off internal sound transmission than that achieved through the MFCA. The slightly higher rate of ABG closure in the TMA group would corroborate this reasoning.

Sound-induced vertigo is another classic symptom of SCDS. A large number of our patients reported this symptom preoperatively (47.3%), with many patients in both groups demonstrating improvement or resolution postoperatively (80% resolution in the MFCA group, 89% in the TMA group).

Generalized vertigo is often reported among patients with SCD.[21] The etiology of generic vertigo and dizziness among patients with SCD is not well understood. This was self-reported vertigo and likely includes disequilibrium and dizziness. For the analysis, we use the word *vertigo*, but we recognize that this is not a precise description of the symptom. Fortunately, both groups showed improvement in this symptom (66% and 62% in the MFCA and TMA groups, respectively). However, resolution rates for unspecified vertigo were lower than the more classic symptom of noise-induced vertigo. Transient dizziness occurs among most patients undergoing procedures that plug the superior semicircular canal due to deafferentation of the superior semicircular canal. Over time, central nervous system plasticity compensates for changes in the dynamics of the vestibular ocular reflex (VOR) in the pitch plane. This typically takes $\geq$6 weeks to resolve. Accordingly, we assessed resolution of this symptom at last follow-up.

Since conductive or mixed hearing loss is common among patients with SCDS, we evaluated the rates of hearing improvement and risk of hearing loss between the groups. There was no pre- to postoperative change in hearing in either group, as measured by ABG, AC, and frequency-specific thresholds. This is consistent with previous reports showing minimal to no improvement in hearing after superior canal defect repair.[22,23] There was a statistically significant closure of the low-frequency ABG in the MFCA group only. This is thought to be due to the increase in BC thresholds following SCD repair, as the BC hyperacusis artifact is resolved, rather than to a true decrease in the AC thresholds. However, it is unclear why this phenomenon occurred only in the MFCA group and not the TMA group. This same finding was demonstrated in other cohorts.[24] Interestingly, even patients with a greater preoperative ABG (>10 dB) did not demonstrate a significant reduction in postoperative ABG. In fact, only 8 patients in the TMA group and 2 patients in the MFCA group experienced an ABG closure ≥10 dB. Accordingly, if a patient with SCD has hearing loss alone, surgery should generally not be recommended, and the patient should be counseled regarding the risk of hearing loss and lack of demonstrable hearing benefit.

While there was little improvement in hearing, there was a small risk to hearing through both approaches. Two of 21 patients (9.5%) in the MFCA group and 3 of 53 patients (5.7%) in the TMA group experienced postoperative worsening of their BC PTA by ≥10 dB. This is likely due to the elimination of the BC hyperacusis rather than to true worsening of hearing.

Complications were uncommon in both groups, and the complication rate in the current study was consistent with rates reported elsewhere in the literature.[15,25] All complications were transient and resolved without long-term sequelae. Given the small number of complications in each group, meaningful statistical comparison between groups was not performed.

There were several limitations to this study. First, this was a retrospective study, and the known shortcomings of any retrospective study were encountered, including incomplete data sets, determination of symptoms and signs through chart review, inconsistent follow-up, and lack of standardization in the treatment paradigm. Second, this was a nonrandomized study, and there may have been reasons why the surgeon preferred one approach or the other for any given patient. In general, the middle fossa procedures were done earlier in the series, and the operating surgeons transitioned to the TMA as their preferred means. Therefore, the TMA group would, by definition, be performed by surgeons with more experience. That said, there may be unrecognized factors that could have confounded the differences seen between the approaches, such as low-lying tegmen, sclerotic mastoid anatomy, large tegmen dehiscence, and patient preferences. Finally, this was a multicenter trial, and there may be some subtle differences in care among centers.

Conclusion

This retrospective multicenter study comparing the outcomes for SCD repair by the TMA or MFCA demonstrated the safety and efficacy of both procedures for the treatment of SCDS. Our data show that in centers where both approaches are offered, the TMA is faster, requires a shorter hospitalization, and is more effective at controlling auditory symptoms (eg, autophony and pulsatile tinnitus) than the middle fossa approach, with no differences in terms of effective control of the vestibular symptoms. The recurrence of symptoms requiring reoperation is low but may be more common among those patients undergoing resurfacing only via a TMA.

Author Contributions

Seth R. Schwartz, substantial contributions to design of project, drafting content, final approval, agreement to be accountable; **Galit Almosnino,** acquisition, analysis, interpretation of data, drafting of work and revising, agreement to be accountable; **Kathryn Y. Noonan,** drafting and revising of content, data acquisition, final approval, agreement to be accountable; **Renee M. Banakis Hartl,** data acquisition, drafting and revising of content, final approval, agreement to be accountable; **Daniel M. Zeitler,** design of project, drafting and revising content, data analysis, final approval, agreement to be accountable; **James E. Saunders,** design of project, drafting and revising content, final approval, agreement to be accountable; **Stephen P. Cass,** design of project, drafting and revising content, final approval, agreement to be accountable.

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References

1. Minor LB, Solomon D, Zinreich JS, Zee DS. Sound- and/or pressure-induced vertigo due to bone dehiscence of the superior semicircular canal. *Arch Otolaryngol Head Neck Surg*. 1998;124:249-258.
2. Minor LB. Clinical manifestations of superior semicircular canal dehiscence. *Laryngoscope*. 2005;115:1717-1727.
3. Friedland DR, Michel MA. Cranial thickness in superior canal dehiscence syndrome: implications for canal resurfacing surgery. *Otol Neurotol*. 2006;27:346-354.
4. Minor LB, Carey JP, Cremer PD, Lustig LR, Streubel SO, Ruckenstein MJ. Dehiscence of bone overlying the superior canal as a cause of apparent conductive hearing loss. *Otol Neurotol*. 2003;24:270-278.
5. Lehmann M, Ebmeyer J, Upile T, Sudhoff HH. Superior canal dehiscence in a patient with three failed stapedectomy operations for otosclerosis: a case report. *J Med Case Reports*. 201; 5:47.
6. Pritchett CV, Spector ME, Kileny PR, Heidenreich KD, El-Kashlan HK. Surgical treatment of hearing loss when otosclerosis coexists with superior semicircular canal dehiscence syndrome. *Otol Neurotol*. 2014;35:1163-1167.
7. Vlastarakos PV, Proikas K, Tavoulari E, Kikidis D, Maragoudakis P, Nikolopoulos TP. Efficacy assessment and complications of surgical management for superior

semicircular canal dehiscence: a meta-analysis of published interventional studies. *Eur Arch Otorhinolaryngol*. 2009;266: 177-186.

8. Ward BK, Agrawal Y, Nguyen E, et al. Hearing outcomes after surgical plugging of the superior semicircular canal by a middle cranial fossa approach. *Otol Neurotol*. 2012;33:1386-1391.
9. Crane BT, Lin FR, Minor LB, Carey JP. Improvement in autophony symptoms after superior canal dehiscence repair. *Otol Neurotol*. 2010;31:140-146.
10. Agrawal SK, Parnes LS. Transmastoid superior semicircular canal occlusion. *Otol Neurotol*. 2008;29:363-367.
11. Gurgel RK, Jackler RK, Dobie RA, Popelka GR. A new standardized format for reporting hearing outcome in clinical trials. *Otolaryngol Head Neck Surg*. 2012;147:803-807.
12. Teixido M, Seymour PE, Kung B, Sabra O. Transmastoid middle fossa craniotomy repair of superior semicircular canal dehiscence using a soft tissue graft. *Otol Neurotol*. 2011;32: 877-881.
13. Schick B, Greess H, Gill S, Pauli E, Iro H. Magnetic resonance imaging and neuropsychological testing after middle fossa vestibular schwannoma surgery. *Otol Neurotol*. 2008;29: 39-45.
14. Shaia WT, Diaz RC. Evolution in surgical management of superior canal dehiscence syndrome. *Curr Opin Otolaryngol Head Neck Surg*. 2013;21:497-502.
15. Gioacchini F, Alicandri-Ciufelli M, Kaleci S, Scarpa A, Cassandro E, Re M. Outcomes and complications in superior semicircular canal dehiscence surgery: a systematic review. *Laryngoscope*. 2016;126:1218-1224.
16. Banakis Hartl RM, Cass SP. Effectiveness of transmastoid plugging for semicircular canal dehiscence syndrome. *Otolaryngol Head Neck Surg*. 2018;158:534-540.
17. Rodgers B, Lin J, Staecker H. Transmastoid resurfacing versus middle fossa plugging for repair of superior canal dehiscence: comparison of techniques from a retrospective cohort. *World J Otorhinolaryngol Head Neck Surg*. 2016;2:161-167.
18. Deschenes GR, Hsu DP, Megerian CA. Outpatient repair of superior semicircular canal dehiscence via the transmastoid approach. *Laryngoscope*. 2009;119:1765-1769.
19. Ung N, Chung LK, Lagman C, et al. Outcomes of middle fossa craniotomy for the repair of superior semicircular canal dehiscence. *J Clin Neurosci*. 2017;43:103-107.
20. Mau C, Kamal N, Badeti S, et al. Superior semicircular canal dehiscence: diagnosis and management. *J Clin Neurosci*. 2018; 48:58-65.
21. Minor LB. Superior canal dehiscence syndrome. *Am J Otol*. 2000;21:9-19.
22. Zhou G, Gopen Q, Poe DS. Clinical and diagnostic characterization of canal dehiscence syndrome: a great otologic mimicker. *Otol Neurotol*. 2007;28:920-926.
23. Ziylan F, Kinaci A, Beynon AJ, Kunst HP. A comparison of surgical treatments for superior semicircular canal dehiscence: a systematic review. *Otol Neurotol*. 2017;38:1-10.
24. Zhang L, Creighton FX, Ward B, Carey JP. A cohort study of hearing outcomes between middle fossa craniotomy and transmastoid approach for surgical repair of superior semicircular canal dehiscence syndrome. *Otol Neurotol*. 2018;39:e1160-e1167.
25. Xie Y, Sharon JD, Pross SE, et al. Surgical complications from superior canal dehiscence syndrome repair: two decades of experience. *Otolaryngol Head Neck Surg*. 2017;157:273-280.