



# Evaluation of the transmastoid plugging approach for superior semicircular canal dehiscences: a retrospective series of 30 ears

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Received: 14 January 2022 / Accepted: 9 February 2022 / Published online: 1 March 2022  
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## Abstract

**Purpose** The classical surgical approach for superior semicircular canal dehiscences (SSCD) is via the extradural middle cranial fossa. This pathway is used to resurface or to plug the SSC. In this paper, we present long-term data on an alternative route: the transmastoid pathway. The predictive factors for a successful surgery are equally presented in this paper.

**Methods** Thirty reports of patients operated between September 2007 to January 2020 were analysed. SSCD was confirmed by the association of concordant complaints, audiometric data, cervical vestibular evoked myogenic potentials (cVEMP) responses and computerized tomography findings. Before and after surgery, the following factors were analysed: auditory and vestibular subjective symptoms, Tullio phenomenon, pure-tone audiometry thresholds for air and bone conduction, air–bone gap, cVEMP threshold, and computerized tomography data, for instance the size of the dehiscence.

**Results** The follow-up is 21 months on average. The transmastoid approach significantly improves all symptoms (although there were less probing results for the vestibular symptoms). Objectively, we can observe, a closure of the audiometric air–bone gap on the low frequencies and an improvement in the cVEMP. The only correlation that was identified was between the preoperative cVEMP results and the postoperative air conduction.

**Conclusions** The originality of this study is the long postoperative follow-up. It allowed us to evaluate the symptoms in the long term and to determine a predictive factor of postoperative complication, which has not yet been described until today. The transmastoid plugging technique is safe and effective. Additional long-term data with a larger cohort are needed to confirm our results and correlation studies.

**Keywords** Transmastoid · Plugging · Superior semicircular · Dehiscence

## Abbreviations

ABG	Air–bone gap	CBCT	Cone beam CT
BC	Bone conduction	CSF	Cerebrospinal fluid
BPV	Benign paroxysmal positional vertigo	cVEMP	Cervical vestibular evoked myogenic potential
CT	Computerized tomography	DVT	Digital volume tomography
		ICU	Intensive care unit

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FIESTA	Fast imaging employing steady-state acquisition
MRI	Magnetic resonance imaging
oVEMP	Ocular vestibular evoked myogenic potential
PPPD	Persistent postural perceptual dizziness
PPV	Positive predictive value
PTA	Pure-tone average
SSC	Superior semicircular canal
SSCD	Superior semicircular canal dehiscence
VEMP	Vestibular evoked myogenic potential
VHIT	Video head impulse test
VNG	Videonystagmography

## Introduction

Superior semicircular canal dehiscence (SSCD) was first described in 1998 by Dr. Lloyd minor [1].

This syndrome is characterized by a set of clinical cochlear and vestibular symptoms. The symptomatic SSCD acts like a third window in the inner ear. Most common symptoms include hyperacusis, autophony, pulsatile tinnitus, and sound or pressure-induced vertigo (Tullio phenomenon and Hennebert's sign). Patients report hearing particularly disturbing internal noises (eyeball movements, footsteps, chewing...) as well as a sensation of auricular fullness. In addition, abnormal posterior endolymphatic flow causes vertigo and sometimes nystagmus. Many patients report chronic disequilibrium. Generally, vestibular symptoms are the main manifestations of the disorder but occasionally only the auditory symptoms are present [2].

High-resolution temporal bone CT scans, or ideally, Cone Beam CT scans (CBCT) (with a better sensitivity) play a central role in diagnosing SSCD [2].

When patients present persistent debilitating symptoms, surgical treatment may be indicated. The goal is to eliminate third window effects, to relieve symptoms and enhance quality of life [2].

The combination of audiometry, vestibular evoked myogenic potentials (VEMP), and CT scanning allows to diagnose this lesion and to analyze whether it can be operated on and which side is the more affected.

The traditional surgical approach is via the middle cranial fossa. This extradural approach permits a direct visualization of the arcuate eminence and the SSCD. However, it is associated with a higher morbidity due to the craniotomy and temporal lobe retraction [3]. During dural elevation, any trauma of the membranous labyrinth may also lead to sensorineural hearing loss (SNHL).

Most otologist surgeons are familiar with transmastoid surgery and the lower morbidity of this approach leads to its growing popularity.

In terms of outcomes, according to a recent meta-analysis [4], there is no statistical significant difference between the middle fossa approach and transmastoid approach.

We present a series of 30 cases of the transmastoid approach, with the longest follow-up analysis in the literature so far. The aim of this study is to analyse its efficiency and its safety as well as to research the potential predictive factors for a successful surgery.

## Materials and methods

A retrospective study from two tertiary referral centers (Sint-Augustinus Hospital, Antwerp, Belgium and Saint-Luc Hospital, Brussel, Belgium) is presented.

Thirty cases operated between September 2007 and January 2020 were included in this study. All patients were listed in an Excel database (Excel, Microsoft, USA).

This study is an ethically approved research (reference: 2021/21OCT/430; Belgian registration number: B 403).

## Clinical management

SSCD was confirmed by the presence of the classical set of symptoms together with positive audiometric, cervical vestibular evoked myogenic potentials and computerized tomography findings.

Only patients with debilitating symptoms of at least 6 months duration, presenting a positive high-resolution CT (HRCT) or CBCT as well as a decreased threshold on cVEMPs (compared to the other side) underwent surgery.

Preoperatively, subjective symptoms were assessed and listed in a database. These symptoms include: autophony, hyperacusis, ear fullness, pulsatile and non-pulsatile tinnitus, sound-induced vertigo (Tullio phenomenon), oscillopsia and disequilibrium. After surgery, audio-vestibular symptoms was classified into three groups: improved, unchanged or aggravated.

An otoscopic examination and general vestibular examination were performed (Hennebert's sign was included).

All patients had a preoperative pure-tone and speech audiogram. Tympanometry was also performed to assess the acoustic stapedial reflexes to exclude otosclerosis and to search for pressure-induced vertigo.

Whenever possible, preoperative computerized videonystagmography (VNG) with caloric testing was performed.

Click-evoked cVEMP measurements are indicative of a positive diagnosis (lower thresholds (<90 dB HL) and higher amplitude). If both sides present a SSCD, surgery is first performed on the side where cVEMP was more abnormal. To confirm the success of surgery, cVEMP was also performed post-operatively, when possible.

All patients underwent high-resolution CT imaging of the temporal bone (0.625 mm thick slices) or a CBCT (0.125 mm thick slices). It was reformatted in the superior SCC plane of Pöschl to confirm the presence of the SSCD and to define the position and size of dehiscence. All CT/CBCT scans also checked for signs of otosclerosis.

After surgery, the plugging was assessed by a postop CT scan or CBCT.

Moreover, we analysed potential surgical complications such as anacusis, permanent SNHL (> 10 dB BC) and facial palsy.

### Statistical analysis

Data analysis was performed with statistical software SPSS statistics v.26 (IBM Corp, 2019). Since most variables did not follow the normal distribution curve, non-parametric tests were used. Bone conduction, air conduction and air–bone gap thresholds were calculated for 0.25, 0.5, 1, 2, 3, and 4 Hz then divided into two categories: the low frequencies correspond to the mean thresholds for 0.25, 0.5, and 1 Hz; the high frequencies correspond to the mean thresholds for 2, 3, and 4 Hz. The Wilcoxon signed-rank test was used to evaluate the evolution of the cVEMP and the audiometry results. A Spearman’s rank coefficient was used to evaluate the correlation between the amount of preoperative complaints, the cVEMP, and the audiometric results. The significance threshold for the Wilcoxon signed-rank test was set at 0.05. To avoid inflating the type I error rate due to the high number of correlations, the significance threshold for the correlations was set at 0.01.

### Surgical technique

A C-shaped postauricular incision is made and a cortical mastoidectomy is performed with identification of the tegmen, sigmoid sinus, lateral semicircular canal, and mastoid antrum. If the dura is low, exposure and bipolar cauterisation helps to retract and elevate the dura. The labyrinth is skeletonized and the superior SCC is blue lined beneath the middle fossa dura. For the plugging, we use an original technique which we called the double “letter box technique”. The ampulla of the superior SCC is blue-lined and an elliptic single opening is created (“letter box”).

The subarcuate artery may be used as a landmark to find the posterior arm of the superior semicircular canal: the distance between the subarcuate artery and the ampulla is twice as great as the distance between the subarcuate artery and the posterior crus [5].

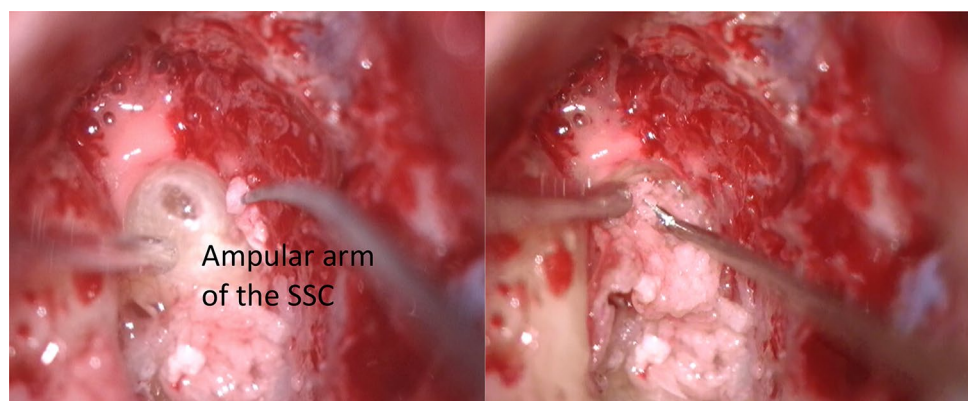
An elliptic fenestration is made at the upper part of the ampulla of the superior SCC arch.

A thin piece of fascia is first used to occlude the lower part of the canal lumen and pushed towards the ampulla (Fig. 1). This fascia is introduced to avoid a perilymphatic leakage and the migration of bone paté into the labyrinth [causing potential benign paroxysmal positional vertigo (BPPV)]. The bone pate [mixed with Tisseel (Fibrin Sealant, Baxter Healthcare Corporation©, Deerfield, IL, USA)] is introduced to further occlude the canal lumen and obtain a bony plug.

A second elliptic fenestration is made in the posterior (non-ampular) part of the superior SCC, and fascia is also introduced and pushed towards the common crus. Bone paté is again used to further plug this second crus of the superior canal and seal this fenestration (Fig. 1).

If needed, a partial coverage of the dura with bone paté at the roof of the mastoid and tegmen is performed to avoid a secondary late meningo-encephalocoele. The wound is closed in layers and a mastoid pressure dressing

**Fig. 1** Elliptic fenestration at the upper part of the ampular arm of the SSC arch. Fascia is used to occlude the canal lumen (left). Then, Bone Paté is used to further plug the canal and seal the fenestration (right)



is applied. The patient can return to the ward room and does not need intensive care.

## Results

### Patient description

Twenty-seven patients operated for SSSD were analysed in this study. The mean age was 52 years (range 27–74 years) with 11 males (40.7%) and 16 women (59.3%). There were 53.3% right ears and 46.7% left ears. All the unilateral operations were primary procedures (no revisions). Three cases underwent bilateral surgery because of a partial improvement of symptomatology after the initial procedure. The total number of surgeries was, therefore, 30. The delay between the two sides in the three bilateral cases was, respectively, 7, 6 and 4 months. In no case was a middle cranial fossa approach for revision or salvage necessary. Postoperative appointments were held at 1 week, 2 weeks, 1, 3 and 6 months, and yearly thereafter. The mean patient follow-up was 21.4 months (range 3–108).

### Subjective complaints

Table 1 outlines the preoperative symptoms, as well as the postoperative outcomes.

The most common preoperative symptoms were: autophonia (29/30) (96.67%), instability/vertigo (24/30) (80%), tinnitus (24/30) (80%) (of which 58.3% were pulsatile), hyperacusis (9/30) (30%).

Hyperacusis improved in 100% of the cases. All but one patient obtained relief from autophonia (28/29) (96.55%). Patients with pulsatile tinnitus were more likely to report improvement (13/14) (92.86%) than those with non-pulsatile tinnitus (11/18) (61.11%). 94.74% (18/19) of the patients complaining of auricular fullness experienced an improvement, but one patient reported no change after surgery (patient 12). One patient developed auricular plenitude after

surgery (patient 16). Disequilibrium improved after surgery in 79.17% (19/24). After contralateral surgery, one patient still felt no improvement (patient 18). In no case was there an aggravation of disequilibrium was after surgery. Oscillopsia and Tullio phenomena were reduced in 81.82% (9/11) and in 89.47% (17/19), respectively.

### Objective parameters

Audiometric data are analysed in Table 2. The mean follow-up period was 19 months (range 3–116 months). Bone conduction, air conduction and air–bone gap thresholds were calculated for 0.25, 0.5, 1, 2, 3, and 4 Hz and then divided into two categories: the low frequencies correspond to the mean thresholds for 0.25, 0.5, and 1 Hz; the high frequencies correspond to the mean thresholds for 2, 3, and 4 Hz.

BC thresholds showed a pseudo-conductive hearing loss, in particular on low frequencies with negative values (250–1000 Hz). Note that for one patient the BC was not measured and that for three patients, the preoperative hearing loss was so profound that the BC could not be measured. We also observed a wide range in AC thresholds. The largest mean ABG was 33,3 dBHL at 250 Hz (range 0–80).

Wilcoxon signed-rank test was used to compare the BC, the AC and the ABG before and after the operation for high and low frequencies separately (Fig. 2). The BC significantly increased for low ( $Z=3.06$ ,  $p=0.002$ ) and high frequencies ( $Z=2.07$ ,  $p=0.04$ ), while the AC significantly diminished for high frequencies ( $Z=2.42$ ,  $p=0.015$ ) but not for low frequencies ( $Z=1.13$ ,  $p=0.26$ ). The ABG significantly diminished for low frequencies ( $Z=3.25$ ,  $p=0.001$ ) but not for high frequencies ( $Z=0.1$ ,  $p=0.9$ ). All means are illustrated in Table 2.

A transitory hearing loss (> 10 dB) was observed during the immediate postoperative period in 5/30 patients (16.7%). One patient (patient 24) had a significant SNHL (> 10 dB HL) 8 months after surgery with a decrease in bone conduction of 40, 45, 30, 15 dB for the 250, 500, 1000 and 2000 Hz respectively.

**Table 1** Preoperative symptoms and postoperative outcomes

	Preoperative		Postoperative		
	Presence	Absence	Improvement (%)	No change (%)	Deterioration (%)
Autophonia	29	1	28 (96.55%)	1 (3.45%)	0 (0%)
Hyperacusis	9	21	9 (100%)	0 (0%)	0 (0%)
Pulsatile tinnitus	14	16	13 (92.86%)	1 (7.14%)	0 (0%)
Non-pulsatile tinnitus	18	12	11 (61.11%)	7 (38.89%)	0 (0%)
Aural fullness	19	11	18 (94.74%)	1 (5.26%)	0 (0%)
Instability/vertigo	24	6	19 (79.17%)	5 (20.83%)	0 (0%)
Oscillopsia	11	19	9 (81.82%)	2 (18.18%)	0 (0%)
Tullio	19	11	17 (89.47%)	2 (10.53%)	0 (0%)

**Table 2** Audiometric and vestibular descriptive results

	Time	Frequency	<i>n</i>	Mean (SD)	Median	Min	Max
Bone conduction	Preoperative	Low frequencies	26	7.44 (14.69)	2.5	−10	45
		High frequencies	25	21.93 (18.84)	15	2.67	65
	Postoperative	Low frequencies	26	16.03 (17.08)	12.5	−1.67	50
		High Frequencies	25	27.47 (19.04)	21.67	5	63.33
	Postoperative—preoperative	Low frequencies	26	8.59 (14.72)	6.67	−15	58.33
		High frequencies	25	5.53 (12.01)	2.67	−11.67	42.33
Air conduction	Preoperative	Low frequencies	30	32 (22.86)	30.83	−3.33	90
		High frequencies	28	31.77 (24.31)	21.33	5	97.33
	Postoperative	Low frequencies	30	30 (24.4)	24.17	1.67	96.67
		High frequencies	28	35.99 (28.02)	24.17	10	110
	Postoperative—preoperative	Low frequencies	30	−2 (13.34)	−3.33	−30	33.33
		High frequencies	28	4.21 (14.54)	5	−38.33	32.67
Air–bone gap	Preoperative	Low frequencies	26	23.78 (14.93)	21.67	0	56.67
		High frequencies	25	7.23 (11.03)	3.33	−5	35
	Postoperative	Low frequencies	26	13.01 (10.83)	10.83	0	45
		High frequencies	25	6.91 (12.26)	2.33	−15	37.67
	Postoperative—preoperative	Low frequencies	26	−10.77 (14.88)	−6.67	−55	11.67
		High frequencies	25	−0.32 (11.93)	0	−26	32.67
cVemp	Preoperative	N/A	11	100.45 (10.11)	95	90	120
	Postoperative	N/A	11	121.36 (12.86)	130	100	135
	Postoperative—preoperative	N/A	11	20.91 (13.19)	20	0	40
Dehiscence size	Preoperative	N/A	30	3.39 (1.08)	3.25	1	5

The low frequencies correspond to the mean thresholds for 0.25, 0.5, and 1 Hz; the high frequencies correspond to the mean thresholds for 2, 3, and 4 Hz

C-VEMP cervical vestibular evoked myogenic potentials

The first seven patients had no preoperative cVEMP. All other 23 patients had preoperative cVEMPs measurements (Table 2). The mean follow-up period was 24 months (range 3–108 months).

Fifteen ears (65.2%) (15/23) had cVEMPs threshold < 90 dB HL. The difference between the two sides was on average 24.3 dB SPL. cVEMPs were reduced bilaterally in 17.4% (4/23) of cases and unilaterally in 60.9% (14/23). However, we found normal cVEMPs bilaterally in 21.7% (5/23).

After surgery, 21 ears were tested for the cVEMP (Table 2), and in 6 of these patients, no response was detected. In the 15 remaining cases, the cVEMP median threshold significantly increased ( $Z = 2.81$ ,  $p = 0.005$ ) from 100 dB SPL (min = 85; max = 125) to 120 dB SPL (min = 100; max = 135). We systematically offered physiotherapy to accelerate vestibular compensation.

Whenever possible (11.1%) (3/27) a VNG was performed and one patient presented preoperative areflexia.

All patients had a preoperative HRCT scan or CBCT of the temporal bone. The mean size of the dehiscence was 3.39 mm (range [1–5 mm]) and 21 patients presented a dehiscence larger than 3 mm. Two cases of superior

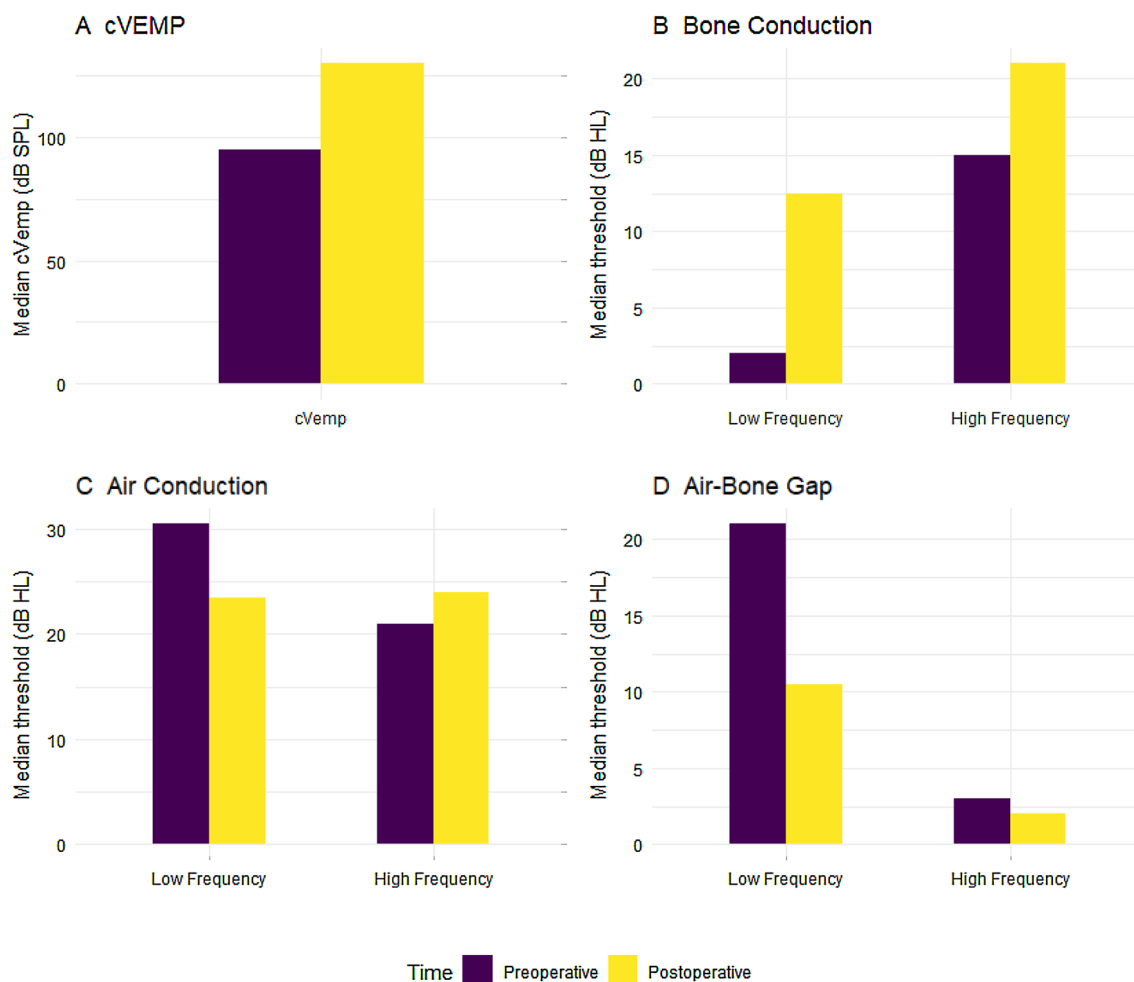
semicircular canal dehiscence were related to a prolapse of the superior petrosal sinus.

Other associated pathologies were: migraine in 3 patients (patient 12bis; 14; and 23), prior head trauma in 2 patients (patient 4 and 13), Eustachian tube dysfunction (patient 12 and 17) and persistent postural perceptual dizziness (PPPD) (patient 23). A contralateral schwannoma was found in patient 11 and a contralateral arachnoid cyst in contact with the acoustic-facial nerves without vascular–nervous conflict was found in patient 24.

A postoperative CT scan was performed in 12 out of 30 patients and an MRI in 12 out of 30 to ensure the correct position of the plugging and to exclude possible complications (Fig. 3). All CT and MRI showed correct plugging (100%). No major complications such as anacusis and facial paralysis were observed but patient 24 presented a significant SNHL (30 dB HL).

## Correlation studies

Spearman's correlations were used to assess the correlation between dehiscence size, the cVEMP data, bone conduction,



**Fig. 2** Preoperative and postoperative data. *C-VEMP* cervical vestibular evoked myogenic potentials. Low frequency: mean thresholds for 0.25, 0.5, and 1 Hz. High frequency: mean thresholds for 2, 3, and 4 Hz

air conduction, air–bone gap, and preoperative subjective symptoms. To avoid inflating type I error rate, the significance threshold was set at 0.01. Only the correlation between the preoperative cVEMP and the increase in high frequencies of the air conduction threshold was significant ( $r_s(22) = 0.54, p = 0.01$ ) (Fig. 4).

## Discussion

In SCCD, symptomatology alone is not sufficient to establish a clear diagnosis.

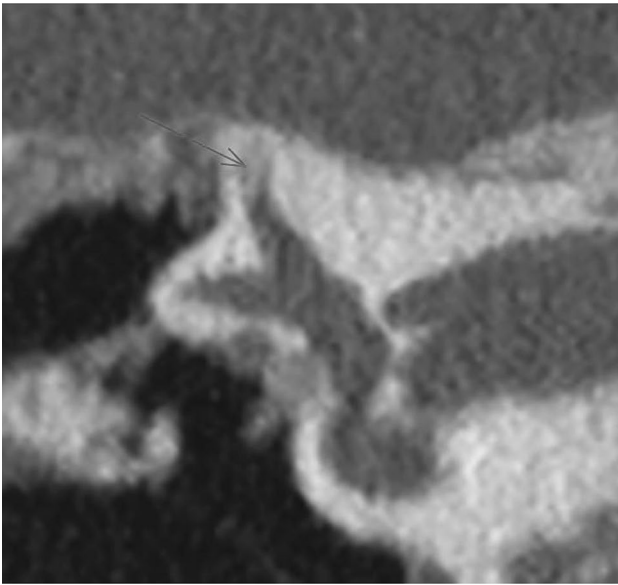
Audiograms with low-frequency conductive hearing loss (predominately below 1000 Hz) and a large air–bone gap at the lower frequencies are indicative [6].

VEMP testing yields a 91.4% sensitivity and 95.8% specificity. It can be used as a practical screening method to establish the most affected side in bilateral SCCD cases.

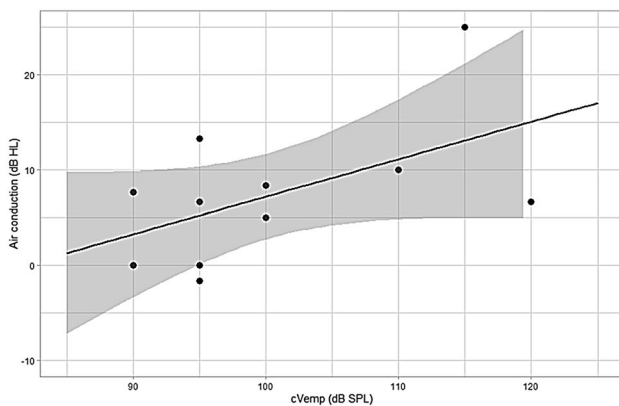
oVEMP responses appear to be more sensitive than cVEMP responses according to a recent study [7].

High-resolution CT scans or CB-CT has a high sensitivity and remains the gold standard in the diagnosis of SCCD [7]. Slice thickness smaller than 0.625 mm and high-resolution CT scans reformatted in the planes of Stenver and Poschl is preferred [2]. Compared to high-resolution multidetector CT, digital volume tomography (DVT) or CBCT significantly reduces radiation exposure. It also has a higher spatial resolution but a longer scanning time, making it prone to motion artefacts. Preoperative MRI helps in the differential diagnosis for endolymphatic hydrops, labyrinthitis or skull base tumors.

Darrouzet et al. [8] observed a caloric deficit before surgery in a third of the cases, this suggests that this disease might involve other labyrinthine structures. It is particularly true in the most long-term disabled patients. Caloric testing and video-head impulse testing could be



**Fig. 3** Coronal reformation of a postoperative CT scan showing the higher density of the superior semicircular canal (green arrow) compared to the vestibule and lateral semicircular canal, ensuring the correct position of the plugging of the ampular crus



**Fig. 4** Correlation between air conduction increase (high frequencies) and preoperative cervical vestibular evoked myogenic potentials (cVEMP)

a prognostic factor for postoperative balance outcome and should be included systematically in future cases. A hypofunctional vestibular apparatus could explain why balance symptoms improve the least after surgery in this patient group. Another explanation could be the presence of other concomitant pathologies. Hence, the importance of a preoperative MRI to exclude a posterior fossa tumor (Schwannoma, arachnoid cyst) or a concomitant endolymph hydrops. Among our patients who had no improvement in vestibular symptoms, two presented concomitant pathologies: one patient with a contralateral schwannoma,

another with a contralateral arachnoid cyst. Migraine also has to be excluded or treated before surgery.

A pan-labyrinthine hypofunction in 1/3 of cases and an impairment of posterior SCC function is observed in 15%, probably because of the plugging material [2]. Possible damage to the cochlea due to the plugging materials could be responsible for high-frequency sensorineural hearing loss [2].

Another explanation for this hypofunction could be due to drilling close to the labyrinth.

Our better results in terms of complications could be related to the surgical technique which aims to introduce fascia before plugging with the bone dust. This could prevent the migration of bony material into the rest of the labyrinth.

As in most studies, we showed that plugging has a high success rate in relieving autophony, Tullio's phenomenon, hyperacusis, auricular fullness, and pulsatile tinnitus [7, 9].

Pulsatile tinnitus responded better than non-pulsatile tinnitus, probably related to the surgical isolation from the meninges and cerebrospinal fluid (CSF) pulsations [7, 9].

Unlike the study by Banakis et al. [10], symptoms of instability improved in 80%. This difference could be explained by our longer follow-up. Nevertheless, these vestibular symptoms improved less than other symptoms. However, we observed no worsening of vestibular symptoms.

In two of the three patients with a bilateral pathology, the imbalance improved after the second contralateral surgery.

We observed a significant closure of the air–bone gap in the low frequencies. This can be explained by a restoration of the BC which was initially supranormal. A small but significant degradation of AC thresholds is shown at high frequencies. Plugging could increase mass reactance, which would be likely to affect the high frequencies.

We observed a significant improvement in cVEMP thresholds.

As shown in the study by Ward et al. [2], plugging seems effective in eliminating the third mobile window and induces a normalization of the cVEMP thresholds. The latter would be sufficient to confirm closure of the third window [6]. Imaging is, therefore, not systematically necessary to confirm closure after surgery.

In our study, no high correlation between cVEMP and audiometric tests was found. This could explain the disproportion between auditory complaints and vestibular complaints.

No correlation was found between symptoms (preoperative or postoperative), audiometric and vestibular tests (preoperative and postoperative) in relation to the size of the dehiscence.

Chien et al.'s study and Yuen et al.'s study [11] found a significant correlation between dehiscence length and maximal ABG.

Recently, Pframmatter et al. confirmed our results and found no significant association between the size of the dehiscence and the pattern of the audiogram. However, they demonstrated a significant correlation between preoperative symptoms and the size of the dehiscence. They also found a correlation between the dehiscence length and the cVEMP thresholds [12].

According to Niesten et al.'s study [8], auditory symptoms were more often associated with larger dehiscences that were closer to the ampulla.

For one patient only, the follow-up was relatively small (3 months). The study was closed in January 2020. Since then, the patient has been seen for regular follow-up and her situation remained stable. From a statistical point of view, it seems that excluding this patient would not influence the overall results.

Darrouzet [8] proposes an intervention for dehiscences larger than 3 mm. Our study did not show a correlation between the size of the dehiscence and the postoperative symptoms or paraclinical tests. In our opinion, the size of the dehiscence is not a decision-making criterion for surgery, but can be a criterion in the choice of the side to operate on in bilateral cases. Unlike other studies, which rely mainly on HRCT, we preferred the use of cone beam CT scan.

Only one significant correlation could be demonstrated, namely a correlation between the preoperative cVEMP thresholds and the improved postoperative air conduction for high frequencies. The more pathological the value of the preoperative cVEMP (lowered threshold), the more this low-impedance pathway for sound pressure entering the oval window will cause dissipation through the vestibular labyrinth instead of the cochlea. Plugging seems to restore impedances to more normal levels by increasing the ground reactance.

Because otologic surgeons are familiar with transmastoid surgery and because of the lower morbidity of this procedure, the transmastoid approach is growing in popularity [10].

According to a recent meta-analysis [4], there is no statistically significant difference between middle fossa and transmastoid approach in terms of outcome. The overall success rate is 94%, the complication rate is low.

The differences are the shorter hospital stay for transmastoid surgery, and the possible adverse events associated with craniotomy and retraction of the temporal lobe for the middle fossa route.

Darrouzet et al. [8] carried out a large study on a series of patients operated on via the middle fossa approach. They demonstrate the good long-term efficiency and the non-invasiveness of direct plugging by MFA.

All patients with SSCD could benefit from transmastoid surgery. The presence of a contracted mastoid and a

low-hanging tegmen can, however, make surgery more difficult. Preoperative imaging should be performed to assess the level of the dura and the degree of potential dural manipulations necessary to do the canal plugging.

In a recent anatomical analysis of tegmen slopes and shapes, 92.4% present a slight overhang of the dura. In this case, we can use a bipolar coagulation to shrink, stretch and elevate the dura. Medial dural elevation has to be avoided to prevent disruption of the membranous labyrinth [9].

To address the opening created by the dehiscence in the skull base, four techniques have been described and are valid for both approaches: plugging, capping, resurfacing and plugging with resurfacing. Also, different materials have been used (cortical bone graft, fascia, bone pate, bone wax or cartilage). Studies suggest that plugging techniques offer better results, a higher success rate and a better control of symptoms [4, 10] Gioacchini et al. 'study [4] observed no significant differences between the different modalities of canal repair regarding success and complications rate.

In terms of plugging material, we prefer fascia in the lower part of the opening followed by bone pâté mixed with Fibrin Glue to seal and occlude the canal in its upper part. In animal studies, bone pâté seems to have the best hearing outcome and the highest degree of periosteal osteoneogenesis at the occlusion site compared with bone wax and muscle [13]. Bone wax may also elicit a foreign body reaction, deleterious for the labyrinth.

## Conclusion

The originality of this study is the long duration of postoperative follow-up. The mean follow-up of the symptoms was 21.4 months. The mean follow-up period was 19 months and 24 months for auditory and cVEMP, respectively. It allowed us to evaluate the symptoms in the long term and to determine a predictive factor of postoperative complication which has not yet been described until today.

The transmastoid plugging technique is safe (no major complication has been identified) and effective with a significant improvement for all symptoms (although less for the vestibular symptoms), a closure of the audiometric air–bone gap for the lower frequencies and an improvement in cVEMPs. The correlation studies showed only a correlation between preoperative cVEMP and postoperative air conduction. This might predict a larger acute frequency impairment after plugging in patients with a higher preoperative cVEMP threshold.

The caloric test primarily evaluates the function of the lateral canal. VHIT should be performed before and after surgery to evaluate the impact of plugging on the entire vestibular system.

Despite different surgical approaches and techniques presented in the literature, additional long-term data with a larger cohort is needed to confirm our results and correlation studies.

**Acknowledgements** I would like to thank Robert Mills for his availability and for commenting on the original manuscript.

**Author contributions** GG and TS wrote the original manuscript followed by all co-authors commenting on the original manuscript and approved the final work. FW handled the database and did the statistical analyses.

**Funding** No funds, Grants, or other support was received. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

**Availability of data and materials** All data and material are available.

## Declarations

**Conflict of interest** The authors have no competing interests to declare that are relevant to the content of this article.

**Ethics approval** This study is a retrospective and ethically approved Research. (Reference: 2021/21OCT/430; Belgian registration number: B 403).

**Consent to participate** All patients give their verbal consented to participate this study.

**Consent for publication** Verbal informed consent was obtained prior to the submission.

**Employment** There is no employment by any organization that may gain or lose financially through publication of this manuscript.

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