Surgical Outcomes of Sigmoid Sinus Resurfacing for Pulsatile Tinnitus: Predictive Value of Water Occlusion Test and Imaging Study

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**Running title:** Pulsatile tinnitus surgery & water occlusion test

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ABSTRACT

Objectives. Sigmoid sinus resurfacing (SS-R) is one of the most effective surgical treatments in patients with pulsatile tinnitus (PT) originating from anatomical variants of the vascular walls in temporal bone. This study aimed to update the clinical outcomes of SS-R and evaluate the efficacy of the water occlusion test (WOT) as an additional diagnosis modality.

Methods. We retrospectively reviewed medical records including tinnitus questionnaires, temporal bone CT (TBCT) scans, audiologic tests, and preoperative WOT results from patients who underwent SS-R.

Results. A total of 26 patients was included in the study. The mean age was 44.0 years with three months of mean symptom duration. Fourteen patients (53.8%) were completely cured, seven (26.9%) were significantly improved, and five (19.2%) were stationary. The mean visual analog scale (VAS) loudness score decreased from 5.26 to 1.34 ($p < 0.001$) and the mean tinnitus handicap inventory (THI) score also improved from 50.23 to 5.5 ($p < 0.001$) after SS-R surgery. In 10 patients with discrepancies between the preoperative TBCT and intraoperative findings, WOT showed a significant additive effect in predicting surgical outcomes. No patients encountered severe intra- or postoperative complications during the entire follow-up period.

Conclusion. SS-R provides significant symptom improvement in patients with sigmoid sinus dehiscence with positive WOT without other sigmoid sinus variants. A combined diagnostic approach with TBCT, WOT, and intraoperative findings is crucial to achieve better surgical outcomes of PT caused by sigmoid sinus variants.

Keywords. Pulsatile tinnitus, Sigmoid sinus resurfacing, Water occlusion test, Prominent mastoid emissary vein
INTRODUCTION

Tinnitus is the perception of sound without external audiologic stimulus that can be categorized into two groups: subjective and objective tinnitus. Objective tinnitus is also classified as vascular tinnitus and non-vascular tinnitus according to the origin. Vascular tinnitus, also known as pulsatile tinnitus (PT), constitutes approximately 10% of all patients with tinnitus[1]. Up to 92% of the cases in PT have underlying demonstrable causes[2], which provides the opportunity to cure symptoms with surgical procedures. The causes of PT are major vascular wall anomalies in the temporal bones[3,4] and there are three potential mechanisms supporting how PT is caused by those anomalies: 1) turbulence of blood flow caused by changes in vascular hemodynamics[5,6], 2) vibration of a dehiscent vascular wall without turbulent flow[7,8], and 3) third-window lesions in the inner ear causing abnormal sound perception[9,10]. Among the various vascular wall anomalies, sigmoid sinus abnormality, with approximately 20% prevalence in PT patients, is considered the most common identifiable cause of venous origin PT[8,11,12].

For the treatment of PT, the importance of accurate diagnosis of the causative anatomical anomaly prior to surgical procedure must be emphasized. History taking, physical examination, audiologic tests, laboratory tests, imaging examination, ultrasonography, and water occlusion tests (WOT) are important tools for accurate diagnosis[13]. The aim of this study is to analyze PT surgical outcomes and to evaluate the efficacy of WOT as a powerful additional tool in the process of diagnosis accompanied with temporal bone CT (TBCT) for determining optimal surgical modalities for vascular wall anomalies causing PT.
MATERIALS AND METHODS

Study patients

We included patients with PT who visited [hospital name] between April 2018 and December 2021 and underwent sigmoid sinus resurfacing (SS-R) surgery. All patients were treated with tinnitus retraining therapy, along with medication including anxiolytics and beta blocker, for a minimum of 3 months. Additionally, any potential metabolic or hemodynamic causes such as hypertension, hyperthyroidism, anemia, etc., were corrected if present. Surgical intervention was determined if there was no improvement in symptoms even after three months of this conservative treatment. For pre-operative evaluation, TBCT and WOT were performed to obtain information about anatomical variations and to plan appropriate surgical methods. Tinnitus visual analogue scale (VAS) loudness (LD), awareness (AW), annoyance (AN), effect on life (EF), and tinnitus handicap inventory (THI) scores from a tinnitus questionnaire were used for comparing subjective outcomes, and pure tone audiograms were also compared for objective pre- and postoperative outcomes. VAS LD score and THI score were analyzed for primary and secondary outcomes, respectively.

Surgical outcomes were classified into four groups according to VAS LD; complete cure when reduction of VAS LD is 100%, significant improvement when between 50-99%, stationary status when between 1-49%, and no improvement when at 0%[4,14]. This study was approved by the Institutional Review Board of the Clinical Research Institute at [hospital name] (KC21RASI0524) and was conducted in accordance with the Declaration of Helsinki.

Water occlusion test
After positioning the patient’s head tilting to the healthy side by about 10 degrees, we filled the external auditory canal of the PT side with a few milliliters of sterilized normal saline solution at body temperature under microscopy. Any changes in tinnitus symptoms were requested from the patients and results of the WOT were classified as positive when PT fully ceased, partial when PT decreased but is still present, and negative when PT shows no change or is worsened by the test[13].

Surgical procedures

SS-R surgery for sigmoid sinus dehiscence (SS-Deh) was conducted using the following steps: 1) simple cortical mastoidectomy, 2) skeletonizing the SS and exposure of the dehiscent area by removing the mucosa, and 3) resurfacing and reinforcing the SS wall using an autologous bone pate and bone cement (Fig. 1A). Other surgical techniques including SS diverticulum obliteration with a periosteal flap (Fig. 1B), jugular bulb resurfacing, or emissary vein ligation (Fig. 1C) were performed in addition to SS-R based on the diagnosis confirmed by the combination of TBCT, WOT, and intraoperative findings.

Statistical analysis

Significant improvements in tinnitus VAS score and THI score were determined using the Wilcoxon signed-rank test. Statistical analyses were performed using IBM Statistical Package for Social Science (SPSS) for windows, version 24.0 (IBM Corp., Armonk, N.Y., USA). Statistical significance was set when $p$-value was lower than 0.05.

RESULTS

Demographics and clinical characteristics
The total number of enrolled patients was 26 (seven men, 19 women), and the mean age was 44 ± 13.8 years (range from 18 to 75 years). Patients’ mean symptom duration was 30.8 ± 39.4 months. Of the 26 patients, 21 had right side tinnitus and five had left side tinnitus. Sixteen patients showed positive results in WOT. Seven patients showed a partial response, and three patients showed negative results in WOT.

Preoperative temporal bone CT scans demonstrated SS-Deh in 23 cases (Fig. 2A), seven sigmoid sinus diverticulum (SS-Div) (Fig. 2B), three dehiscent high riding jugular bulb (HJB-Deh), and six prominent mastoid emissary vein (PMEV) (Fig. 2C) cases.

Mean postoperative follow up duration was 13.2 ± 8.3 months. Every patient underwent SS-R surgery and additional surgery according to the final PT diagnosis and WOT results. Patient demographic characteristics and surgical outcomes are summarized in Table 1.

**Surgical outcomes**

Overall subjective surgical outcomes were as follows: 14 patients (53.8%) showed complete cure of tinnitus, 7 patients (26.9%) showed significant improvement, 5 patients (19.23%) showed stationary status, and no patients showed no improvement. Mean (SD) VAS LD score was significantly improved from 5.26 (2.03) to 1.34 (1.85) \( (p < 0.001, \text{Wilcoxon signed-rank test}) \) and other VAS scores, described in Figure 3A, also showed significant improvement after SS-R with or without accompanying surgeries \( (p < 0.001, \text{Wilcoxon signed-rank test}) \) (Fig. 3A, B). Mean (SD) THI score also improved from 50.23 (23.68) to 5.5 (12.74) \( (p < 0.001, \text{Wilcoxon signed-rank test}) \) (Fig. 3C, D).

Upon pure-tone audiograms, 13 patients showed pseudo-low frequency hearing loss (an ipsilateral hearing threshold greater than 10 dB HL at both 250 and 500 Hz, or greater
than 20 dB HL at either 250 or 500 Hz compared with the contralateral side)[15] in the ipsilesional ear and improvement of hearing threshold was shown in 12 patients.

In 10 patients, there were discrepancies between the preoperative TBCT and intraoperative findings as follows: eight cases of SS-Deh were in actuality cases of thin SS plate, three cases of PMEV were not prominent in mastoid cavity, and one case of SS-Div was not an actual diverticulum. Among these 10 patients, nine patients achieved successful surgical outcome based on the result of WOT. Even though the intraoperative results were a thin SS plate, when SS-R was performed according to positive WOT results, four complete and two significant results were obtained. One patient who underwent SS-R even with negative WOT results showed stationary results. One patient whose intraoperative finding was thin SS plate with SS-Div managed by SS-R with SS-Div obliteration with a periosteal flap[16] according to negative WOT results showed complete results. One complete result and one significant result were also achieved when only a SS-R was performed following positive WOT results in two patients whose PMEV was identified only on TBCT but not specially managed intraoperatively.

Interestingly, cure rate of SS-R surgery in patients with PT caused by SS-Deh alone demonstrating positive TBCT and intraoperative findings along with positive WOT was up to 66.7% and the rest of these patients also showed a significant improvement, which indicates the excellent prognostic value of the combined approach with TBCT, WOT and intraoperative findings for the surgical outcomes of SS-R.

Postoperatively, there were no complications except for one case (No.13 in Table 1) of newly developed mild conductive hearing loss (Fig. 4).
DISCUSSION

In this study, we found a high success rate of SS-R in patients with PT originating from sigmoid sinus variants. Out of the total 26 enrolled patients, 21 patients (80.76%) demonstrated a considerable degree of improvement in symptoms following surgery. Furthermore, the study aimed to validate the prognostic value of WOT, previously published by our research group[13], by analyzing the surgical outcomes of SS-R in PT patients based on the results of WOT. However, there were five patients who showed stationary surgical outcomes even with preoperative diagnosis using TBCT, intraoperative findings, and WOT. The first patient (number 6, Table 1) with preoperative TBCT and intraoperative finding of SS-Deh and SS-Div underwent only SS-R, which resulted in a stationary outcome. In this patient, the WOT result was partial, which indicated that her SS-Div had an actual impact on PT symptoms; therefore, sigmoid sinus reshaping to decrease the turbulence in the SS-Div or obliteration with a periosteal flap might be needed to achieve successful surgical outcomes. As previously reported, the reason for partial results in WOT, supporting the impact of SS-Div on symptoms, is that water occlusion of the external auditory canal (EAC) only reduces sound coming from the venous sinus dehiscence but remains or even enhances turbulence sounds originating from SS-Div, PMEV or arteriovenous fistula(AVF)[13]. In more detail, pulsatile sound produced from the venous sinus dehiscent site is transmitted to the tympanic membrane through air transmission(air pulsation mechanism), while pulsatile sound produced from turbulent blood flow can be transmitted directly to the cochlea through bone conduction(turbulence conduction mechanism). In view of the fact that water occlusion of the EAC only effects movement of the tympanic membrane, SS-Deh and HJB-Deh may demonstrate positive results in WOT, whereas SS-Div, PMEV and arteriovenous fisula may demonstrate partial or negative results in WOT.
The mastoid emissary vein (MEV) is a normal venous structure connecting the extracranial venous system and sigmoid sinus[17] that is found in the majority of the population and most often has no significant clinical features[18]. Kim et al. reported that the prevalence of MEV was 74% on the left side and 81% on the right side, and the mean mastoid emissary foramen diameter was 1.73 mm[19]. Forte et al. measured the internal foramina of sigmoid sinuses with 50 normal cadaver skulls and reported that 60% had smaller than 2 mm diameter and 85% had smaller than 3.5 mm diameter[18,20]. Even though most MEVs show no significant clinical features, MEVs with a diameter large enough to produce turbulence might contribute to PT. In our study, TBCT revealed six cases of PMEV and the mean diameter was 2.72 mm. Among them, two patients (numbers 15 and 16, Table 1) had only PMEV which is contributing PT with diameters of 2.59 mm and 2.4 mm respectively, and their WOT results were both partial. One patient underwent only SS-R and the other underwent SS-R with emissary vein ligation surgery. Their surgical outcomes were both stationary; however, changes of THI score were different with 100% increasing and 97% reduction of THI score, respectively. Based on this interesting result, we propose that the confirmed diagnosis of PMEV through various diagnostic tools, including WOT, needs to be managed by emissary vein ligation surgery for symptom relief.

In one patient (number 13, Table 1) who showed SS-Deh, HJB-Deh, and PMEV on TBCT preoperatively, was confirmed to have thin SS plate and HJB-Deh intraoperatively. According to the positive WOT results in this patient, only SS-R and HJB-R were performed and the surgical outcome was stationary with the reduction of 14.2% in VAS LD and 58.2% in THI. However, there was a limit in the evaluation of surgical outcome in this patient due to the occurrence of mild conductive hearing loss after the surgery, probably caused by mild disturbance of air conduction related with resurfacing materials.
The last patient (number 26, Table 1) who showed SS-Deh on preoperative TBCT and in actuality was found to have a SS thin plate intraoperatively showed negative WOT results. The stationary result of surgery in this patient indicates the clinical prognostic value and importance of WOT once again.

Through the analysis of 10 cases that showed discrepancies between preoperative TBCT and intraoperative surgical findings and the five cases with stationary results, we recognized that there is a limitation in diagnosing an anatomical abnormality by TBCT and intraoperative findings in terms of predicting the surgical outcomes of PT.

Therefore, we propose that a comprehensive diagnostic evaluation for pulsatile tinnitus, including preoperative TBCT, WOT, and intraoperative findings, may be necessary to determine the optimal surgical methods and achieve successful surgical outcomes. While the previous report focused more on demonstrating the diagnostic value of a novel WOT based on the possible mechanisms of pulsatile tinnitus[13], we would like to place a greater emphasis on the value of WOT in determining surgical methods, along with surgical findings and outcomes in this study.

There are some limitations in our study, which should be evaluated and addressed in the future. First, this is a retrospective study with a relatively small sample size and all surgeries were performed by a single surgeon in a single institution. A prospective study with a larger sample size and data collected from SS-R surgeries performed at different hospitals by multiple surgeons using the same method needs to be conducted in the future. Second, only subjective outcomes were analyzed for evaluating surgical outcomes in this study. Objective outcomes such as provided by Lee et al.[21] should be considered for the analysis of PT. Finally, there might be a limitation in the evaluation of surgical management efficacy of PMEV in this study since there was only one patient. Data from more patients with PMEV
causing PT who are managed by emissary vein ligation surgery are needed to evaluate its surgical outcome.

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**Author contributions**
Supervision: JHS, SYP, SNP. Validation: SNP, JHL, JSH. Visualization: SNP, JHL, JSH. Writing – original draft: JHL, JSH. Writing – review & editing: all authors.
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13


Table 1. Clinical features and demographic data of 26 patients

<table>
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<th>No.</th>
<th>Sex/Age (yrs)</th>
<th>Tinnitus duration (month)</th>
<th>Side</th>
<th>Diagnosis (TBCT)</th>
<th>MEV diameter</th>
<th>Water occlusion test</th>
<th>Operation</th>
<th>Outcomes</th>
<th>% of outcome (LD)</th>
<th>% of outcome (THI)</th>
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FIGURE LEGENDS

**Fig 1.** Multiple surgical methods for the treatment of pulsatile tinnitus. (A) Sigmoid sinus resurfacing surgery with surgical, autologous bone pate and bone cement for the treatment of sigmoid sinus dehiscence. (B) Obliteration with an inferiorly based periosteal flap for the treatment of sigmoid sinus diverticulum. (C) Ligation of the vein for the treatment of prominent mastoid emissary vein.

**Fig 2.** Representative axial temporal bone CT images of the right temporal bone showing various causes of pulsatile tinnitus. (A) Sigmoid sinus dehiscence(arrow). (B) Sigmoid sinus diverticulum(arrows). (C) Prominent mastoid emissary vein (arrow).

**Fig 3.** Surgical outcomes. (A) Pre- and postoperative improvements in visual analogue scale score. (B) Pre- and postoperative changes in visual analogue scale loudness score. (C) Pre- and postoperative improvements in tinnitus handicap inventory score. (D) Pre- and postoperative changes in tinnitus handicap inventory score.

**Fig 4.** Pre- and post-operative pure tone audiograms of a patient managed with sigmoid sinus resurfacing and high-jugular bulb resurfacing who showed newly developed conductive hearing loss as a complication of the surgery.
A
SS-resurfacing (SS-R)

B
Pericentral flap plugging

C
Emissary vein ligation
Figure 3A, 3B

A. VAS scores

B. VAS loudness