



Physical and psychological outcomes of simple sigmoid sinus bony wall repair for pulsatile tinnitus due to sigmoid sinus wall anomalies

Chen Zhang^{1,2} · Qiang Li^{1,2} · Shufeng Li^{1,2}

Received: 10 January 2019 / Accepted: 11 March 2019 / Published online: 16 March 2019
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

Abstract

Purpose Pulsatile tinnitus (PT) due to sigmoid sinus wall anomalies (SSWA) is a common health disorder. The purpose of this study is to investigate the efficiency of simple sigmoid sinus bony wall repair on tinnitus relief and psychological improvement.

Methods Nine cases of PT due to SSWA were retrospectively reviewed. All of these cases had defect of sigmoid sinus bony wall with or without diverticulum in high-resolution CT. The bony defects were repaired by multi-layer materials, i.e., temporalis fascia, bone dust and another layer of bone dust. The assessment of visual analog scale (VAS) of tinnitus and Mandarin version of the tinnitus questionnaire (MTQ) were carried out before operation and at 1 week, 3 months, 6 months and 12 months after operation.

Results All of eight cases treated by simple sigmoid sinus bony wall repair reported disappearance or significant relief of PT after operation. The VAS and MTQ scores at 1 week, 3 months, 6 months and 12 months after operation all significantly decreased when compared to that before operation ($p < 0.05$).

Conclusion Simple repair of sigmoid sinus bony wall defects was an effective way to reduce the physical impact as well as the psychological impact of PT due to SSWA. The defect of sigmoid sinus bony wall played a key role in the pathophysiology of PT due to SSWA.

Keywords Pulsatile tinnitus · Sigmoid sinus wall anomalies · Sigmoid sinus bony wall repair · Visual analog scale · Tinnitus questionnaire

Introduction

Tinnitus, as a common health disorder, is the perception of sound without external acoustic stimuli. There is a potential impact on patient's quality of life. Pulsatile tinnitus (PT) is an objective tinnitus, and it accounts for less than 10% of tinnitus [1]. PT, differing from subjective tinnitus, can be perceptible to the examiner. Holgate et al. firstly referred the term to the self-perception of a vascular somatosound [2].

There are two persuasive mechanisms of PT. One is audible turbulence which caused by blood flow accelerates or changes in blood flow disrupt laminar flow, such as acquired

dural vascular lesions [3] or aberrant carotid artery [4]. The other is more intensely perception of normal flow sounds which caused by increased bone conduction or decreased masking effect of external sounds [5], such as third mobile window syndrome. Sigmoid sinus wall anomalies (SSWA), including sigmoid sinus diverticulum (SSD) and sigmoid sinus wall dehiscence (SSWD), are the most common identifiable causes of PT [6]. SSD contains well-restricted areas where the sigmoid sinus has eroded into the adjacent mastoid air cells or mastoid cortex through the dehiscence sigmoid sinus wall [7, 8], and SSWD means isolated bone defects of the sigmoid sinus wall without the emergence of a diverticulum [9, 10].

Epidemiologically, PT due to SSWA might have female predominance [11, 12] and right-side predominance [9, 11, 13–15]. A hypothesis is that SSWA have a relationship with idiopathic intracranial hypertension (IIH), associated with sex, obesity, and weight gain [16–18]. One study presented that jugular foramen is larger in females and on the right side [19],

✉ Shufeng Li
lisl@fudan.edu.cn

¹ Department of Otolaryngology-Head and Neck Surgery, Eye and ENT Hospital of Fudan University, Shanghai, China

² NHC Key Laboratory of Hearing Medicine, 83 Fenyang Road, Shanghai 200031, China

which might lead to a possible turbulent blood flow and then increase the risk for SSWA.

Some techniques for treatment of PT due to SSWA have been proposed, including endovascular intervention [20–24] and surgical techniques [7, 9, 10, 14]. Endovascular intervention can rectify turbulence by embolizing the diverticulum with coils or stents. It has the advantages of instant feedback for resolution of symptoms and confirmation for sufficient postprocedural vessel patency. However, it might cause coil migration, intracranial hypertension, and thrombosis. In addition, it has no way to repair SSWD [16]. Surgical techniques include sigmoid sinus wall reconstruction, and craniectomy reconstruction with U clips and Gelfoam hemostatic sponge. The approach of craniectomy reconstruction with U clips was performed in only one patient by Gologorsky et al. [25]. Although no complications were reported with this technique, there was no mention of follow-up period and it might lead to increased risks of massive bleeding or dural injury [23]. Sigmoid sinus wall reconstruction, as a transtemporal and extraluminal approach, was presented in 2007 [7]. Otto et al. reconstructed the sigmoid sinus wall and eliminated audible turbulence via filling the sigmoid sinus diverticulum with fascia and bone wax. The study showed that all three patients underwent surgical intervention and had successful resolution of TP. In other studies, several kinds of materials, such as muscles, dermal replacement tissues, or fascia, were placed either deep in the epidural space of posterior petrous face or directly onto the exposed sinus wall. Then, the sinus wall was further strengthened with bone cement, bone dust, suture, mini-plate, or a combination of these. The superiority of surgical technique is the reduction of coil migration and thrombosis. Sigmoid sinus bony wall repair, a simplified technique of sigmoid sinus wall reconstruction, only resurfaces the bony wall of the sigmoid sinus with temporalis fascia and bone dust by a transmastoid approach, without external compression of the diverticulum or the excision of the diverticulum and the reconstruction of the sigmoid sinus between the sigmoid sinus wall and vein.

This study reports the psychological and physical outcomes of nine PT patients with SSWA treated with sigmoid sinus bony wall repair. Meanwhile, we discuss the predominant pathophysiology between sigmoid sinus diverticulum and sigmoid sinus bony wall defects, and the choices of surgical techniques for patients with SSWA between sigmoid sinus wall reconstruction and sigmoid sinus bony wall repair.

Materials and methods

Demographic information

A retrospective study was undertaken on PT patients hospitalized in the Eye and ENT Hospital of Fudan University

between August 2014 and December 2017. Nine cases of PT due to SSWA treated with sigmoid sinus bony wall repair by the senior author were included in this study. All patients described the tinnitus as a loud pulse-synchronous noise, the intensity of which could decrease by turning heads to contralateral sides or pressing the jugular vein. All patients underwent otoscopic, audiometric, tympanometric evaluations and temporal bone high-resolution computed tomography (CT). There was no hearing loss and middle ear disorder in these patients. This study was approved by the Ethics Committee of the Eye and ENT Hospital of Fudan University.

Surgical technique

A postauricular incision was made, and an anteriorly based periosteal flap created to expose the mastoid cortex. A cortical mastoidectomy was performed and bone dust was collected before the air cells were opened, and the sigmoid sinus was identified and roughly skeletonized. Based on the findings in HRCT, the defect on sigmoid sinus bony wall was located. The sigmoid sinus at this area was further skeletonized to the solid bone wall. A large piece of temporalis fascia was harvested. A small part of it was used to cover the bony defect. Bone dust was then compacted on the fascia as well as the bone wall of the sigmoid sinus around the bony defect. At last, the left large piece of fascia was used to cover the bone dust and secured by Gelfoam and fibrin glue. The air cells are ensured to ventilate to antrum, or filled with bone dust to eliminate dead space.

Postoperative condition of pulsatile tinnitus

To know the postoperative condition of tinnitus, we presented a question with six options to the patients at the last inquisition: (1) the tinnitus has disappeared; (2) the loudness of tinnitus has decreased; (3) the loudness of tinnitus has increased; (4) the tinnitus has disappeared, but a new sensation of tinnitus has appeared and its rhythm differed with the heartbeat; (5) the frequency of tinnitus has decreased, but a new sensation of tinnitus has appeared and its rhythm differed with the heartbeat; (6) the tinnitus has no change.

Visual analog scale

Visual analog scale (VAS) is a subjective psychometric response scale. In this study, it was used to assess the awareness, loudness and annoyance of tinnitus [26, 27], as well as its effect on daily life. The patients were asked to express their tinnitus symptoms by putting a mark along a line ranging from zero to ten. Zero indicated patients were not aware, not audible, not annoyed, and their life was not affected by tinnitus at all, while ten indicated the patients were

completely aware, considerably loud, extremely annoyed, and their life was affected by tinnitus all the time.

Mandarin tinnitus questionnaire

The tinnitus questionnaire (TQ), developed by Hallam in 1987, is one of the most frequently used questionnaires for a psychometric analysis of tinnitus. In this study, the Mandarin version of the tinnitus questionnaire (MTQ) was applied to evaluate the outcome of sigmoid sinus bony wall repair, which had been demonstrated to have good reliability and validity [28]. The MTQ contains five dimensions that assess tinnitus-related psychopathological symptoms: (1) emotional distress (11 items, ED); (2) auditory perceptual difficulties (eight items, AP); (3) cognitive distress (six items, CD); (4) sleep disturbance (six items, SD); and (5) intrusiveness (six items, IN). The MTQ and VAS were completed before operation and at 1 week, 3 months, 6 months and 12 months after operation in clinic or by mail.

Data analysis

Descriptive and comparative statistics of patients were calculated using GraphPad Prism 7.00 (GraphPad Software, La Jolla, California). The scores of VAS and MTQ at different periods were evaluated using repeated-measure of one-way ANOVA with post hoc Bonferroni correction. A *p* value less than 0.05 denotes a statistically significant difference.

Results

As summarized in Table 1, this study included nine female patients. The mean age at presentation was 43.1 years, ranging from 33 to 58 years. The mean duration of PT was 1.5 years, ranging from 0.3 to 3 years. The mean pure tone audiometry (PTA, 0.5, 1 and 2 KHz) was 19.8 dBHL of air conduction/13.6 dBHL of bone conduction on the affected side, and 17.8 dBHL/12 dBHL on the healthy side, respectively. There was no significant difference between PTA of the affected side and that of the healthy side (AC: *p* = 0.134; BC: *p* = 0.294). PT affected the right side in seven of nine patients (77.8%) and the left side in two of nine patients (22.2%). Of nine patients, three patients (33.3%) had SSWD on CT, four patients (44.4%) had SSD, and two patients (22.2%) had both SSWD and SSD in different location. Population descriptive statistics are shown in Table 2.

Sigmoid sinus wall repair was successfully completed in eight of nine patients. One patient had anteriorly and laterally located sigmoid sinus extruding out of the mastoid. The procedure was aborted because a severe bleeding occurred during the elevation of the retroauricular periosteal flap. In the other eight patients, in five patients (62.5%) PT totally disappeared, in two patients (37.5%) the loudness of PT significantly decreased, and in one patient (12.5%) the loudness of PT significantly decreased but a new sensation of tinnitus appeared later.

Table 1 Case information

Case number	Age	Gender	Duration (years)	Side	Pre-op PTA (dBHL) (side: AC/BC)	Diagnosis	Surgical outcome	Post-op condition of tinnitus
1	36	Female	3	R	R: 18/11 L: 18/11	SSWD	Success	Decrease, followed by new tinnitus
2	44	Female	0.5	R	R: 16/6 L: 15/8	SSWD	Success	Disappearance
3	49	Female	3	R	R: 33/30 L: 23/18	SSD	Success	Decrease
4	35	Female	0.8	R	R: 16/16 L: 15/15	SSD and SSWD	Success	Disappearance
5	39	Female	3	L	R: 18/11 L: 16/10	SSD and SSWD	Success	Decrease
6	33	Female	2	L	R: 16/8 L: 16/8	SSD	Success	Disappearance
7	58	Female	0.5	R	R: 25/10 L: 20/10	SSD	Success	Disappearance
8	52	Female	0.5	R	R: 15/13 L: 15/12	SSWD	Success	Disappearance
9	42	Female	0.3	R	R: 23/18 L: 20/15	SSD	Failure	NA

PTA Pure tone audiometry, AC air conduction, BC bone conduction, SSWD sigmoid sinus wall dehiscence, SSD sigmoid sinus diverticulum

Table 2 Demographic descriptive statistics

Characteristics	Total
Age	43.1 (33–58)
Gender	
Female	9
Male	0
Duration	1.5 (0.3–3)
Pre-op PTA (AC/BC)	
Affected side	19.8/13.6
Healthy side	17.8/12
Side	
R	7 (77.8%)
L	2 (22.2%)
Diagnosis	
SSWD	3 (33.3%)
SSD	4 (44.4%)
SSD and SSWD	2 (22.2%)
Surgical outcome	
Success	8 (88.9)
Failure	1 (11.1%)
Post-op condition	
Disappearance	5 (62.5%)
Decrease	2 (25%)
Increase	0
Disappearance, followed by new tinnitus	0
Decrease, followed by new tinnitus	1 (12.5%)
No change	0

PTA pure tone audiometry, AC air conduction, BC bone conduction, SSWD sigmoid sinus wall dehiscence, SSD sigmoid sinus diverticulum

For all eight patients treated with sigmoid sinus bony wall repair, the VAS scores of tinnitus awareness, tinnitus loudness, tinnitus annoyance, and effect of tinnitus on daily life significantly decreased after operation (Fig. 1a–d). Tinnitus awareness at 1 week, 3 months, 6 months and 12 months after operation significantly decreased when compared to that before operation ($p=0.0012$, $p=0.0032$, $p=0.0007$, $p=0.0036$, respectively; Fig. 1a). Significant decrease also occurred in tinnitus loudness ($p=0.0005$, $p=0.0047$, $p=0.0049$, $p=0.0030$, respectively; Fig. 1b), tinnitus annoyance ($p=0.0018$, $p=0.0031$, $p=0.0015$, $p=0.0020$, respectively; Fig. 1c), and effect of tinnitus on daily life ($p=0.0010$, $p=0.0081$, $p=0.0150$, $p=0.0039$, respectively; Fig. 1d). Additionally, The MTQ scores significantly decreased after operation (Fig. 2a–f). ED at 1 week, 3 months, 6 months, and 12 months after operation were all significantly decreased when compared to that before operation ($p=0.0004$, $p<0.0001$, $p=0.0001$, $p=0.0047$, respectively; Fig. 2a). Significant decrease also occurred in AP ($p=0.0034$, $p=0.0044$, $p=0.0043$, $p=0.0286$, respectively;

Fig. 2b), CD ($p=0.0038$, $p<0.0001$, $p=0.0004$, $p=0.0074$, respectively; Fig. 2c), SD ($p=0.0075$, $p=0.0145$, $p=0.0125$, $p=0.0374$, respectively; Fig. 2d), IN ($p=0.0006$, $p=0.0006$, $p=0.0007$, $p=0.0045$, respectively; Fig. 2e), and total MTQ ($p<0.0001$, $p<0.0001$, $p<0.0001$, $p=0.0022$, respectively; Fig. 2f).

Discussion

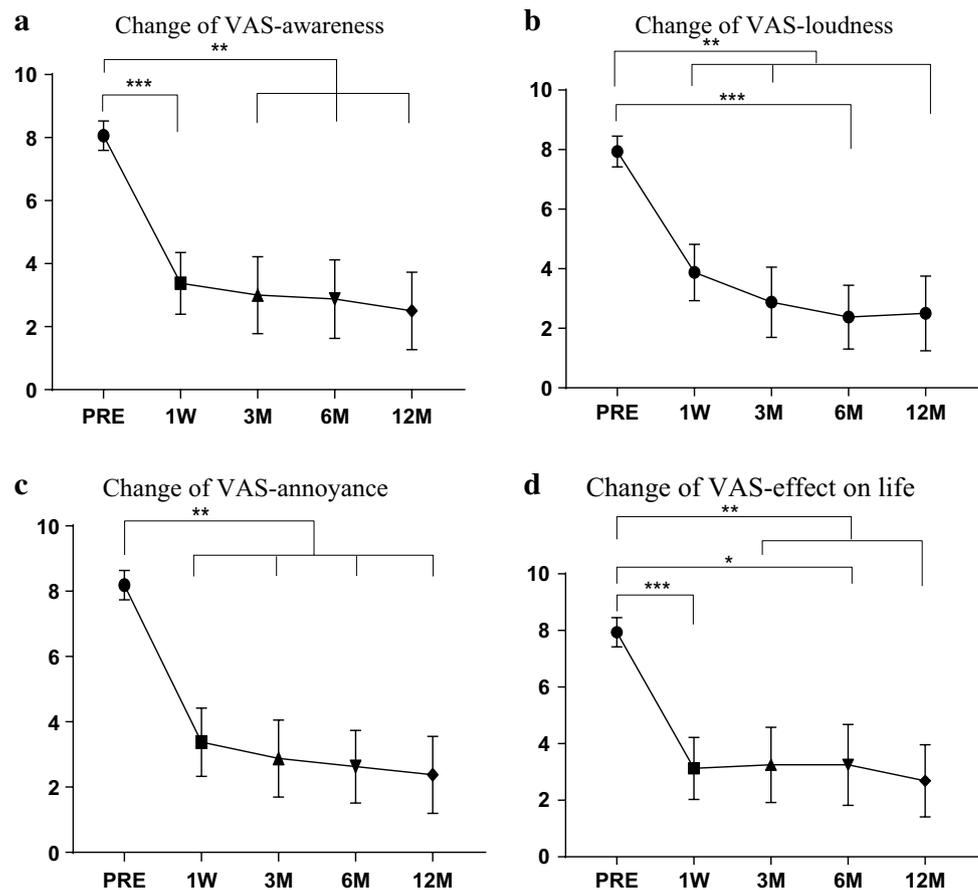
In the present study, we evaluated both the physical and psychological impacts of PT due to SSWA treated with sigmoid sinus bony wall repair. Our findings suggest that sigmoid sinus bony wall defects play a key role in the pathophysiology of PT due to SSWA, and that a simple repair of the sigmoid sinus bony wall is effective for patients with PT due to SSWA.

The VAS scores decreased significantly after the repair of SSWD, and the decreased VAS scores remained unchanged 1 year after the operation. These results suggest that the repair of SSWD is a reliable way to treat PT due to SSWA. In addition, all the MTQ scores decreased significantly after the operation and remained unchanged at 1 year, which demonstrates that the repair of SSWD effectively resolves both the psychological and physical impacts caused by PT. One year after the operation, CT images also suggested that the repair using compound materials was durable.

As it previously described, females and the right side are dominant for the possibility of SSWA. In this study, female predominance and right-side predominance were confirmed. A systematic review demonstrated that females accounted for 90.4% of 139 patients with SSWA and that 65.8% experienced PT on their right side [29]. The rates of female and right-side predominance were lower than in our study, where 100% were female and 77.8% was on the right side, which might result from the relatively few cases in our study. One study indicated that the exocranial area of the right jugular foramen was significantly larger than that of the left and that the volume of the jugular foramen was significantly larger on the right side [30]. Consequently, the larger flow volume creates impact strength to the bone wall forcefully and continuously. Meanwhile, some factors, such as age, dyslipidemia, and intracranial hypertension, can alter the hemodynamics of the sigmoid sinus, increasing the possibility of sigmoid sinus injuries and local turbulence. With the passage of time, the sigmoid sinus wall becomes thin and even dehiscent, and then a diverticulum begins to emerge though the dehiscent bone wall and turbulent blood flow resonates with the air cells. As a result, the sound may be transmitted to the ear though bone conduction.

There is still no consensus on the surgical management of PT due to SSWA. PT is thought to be the sound generated from the turbulent blood flow and transmitted

Fig. 1 Preoperative and post-operative visual analogue scale (VAS) scores of pulsatile tinnitus. The VAS scores including VAS-awareness (a), VAS-loudness (b), VAS-annoyance (c), and VAS-effect on life (d) significantly decreased at 1 week (1W), 3 months (3M), 6 months (6M) or 12 months (12M) after operation when compared to preoperative ones (PRE). There was no significant difference among different VAS scores at different time after operation, respectively. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$



to the middle ear by air conduction or to the inner ear by bone conduction [31]. Based on this hypothesis, some authors have suggested eliminating the turbulence by treating the diverticulum with excision [7] or bipolar cautery [32], or even with an endovascular intervention [20–24]. Sigmoid sinus constriction by cartilage or other materials is also used to reduce the cross-sectional area of the sigmoid sinus [9, 16, 17]. These surgical techniques all achieve significant relief from tinnitus in most PT patients. However, as shown in our study, all PT patients have sigmoid sinus bony wall defects in HRCT. A simple repair of the sigmoid sinus bony wall achieved tinnitus relief in all cases treated using this technique, while the turbulent blood flow remained. In addition, certain materials were used in the treatment of a diverticulum and constriction of the sigmoid sinus to cover the surface of the sigmoid sinus. The procedures for applying these materials actually repaired the defects of the sigmoid sinus bony wall. It is well known that sigmoid sinus anomalies are often found on temporal bone CT scans. In such patients, turbulent blood flow exists in the sigmoid sinus because of the irregular shape of the lumen. However, PT is very rare in these patients. Taken together, the sound of pulsatile blood flow is transmitted through the defect on the sigmoid sinus wall

en route to the inner ear, which generates PT, and sigmoid sinus wall defects might be the predominant cause of PT due to SSWA.

In line with our study, a previous study also suggested that a simple repair of SSWD without any intervention for SSD could completely eliminate PT [11]. In our study, patient 4 and patient 5 had SSWD and SSD simultaneously in different locations of the sigmoid sinus wall (Fig. 3). PT disappeared after the repair of SSWD regardless of the existence of SSD, further suggesting that SSWD, but not SSD, played a key role in the generation of PT. A simple repair of the sigmoid sinus bony wall was effective for treating PT due to SSWA in our study, as well as in other studies [14]. Other procedures that aim at reducing or eliminating the turbulence of blood flow in the sigmoid sinus might be unnecessary. Additionally, these procedures carry the risks of venous hemorrhage and elevated intracranial pressure when compared to a simple repair of the sigmoid sinus bony wall.

There were some limitations to our study. The number of cases was small, and the follow-up period was relatively short. Future studies enrolling many cases and hospitals and a longer follow-up period are essential to confirm our theory.

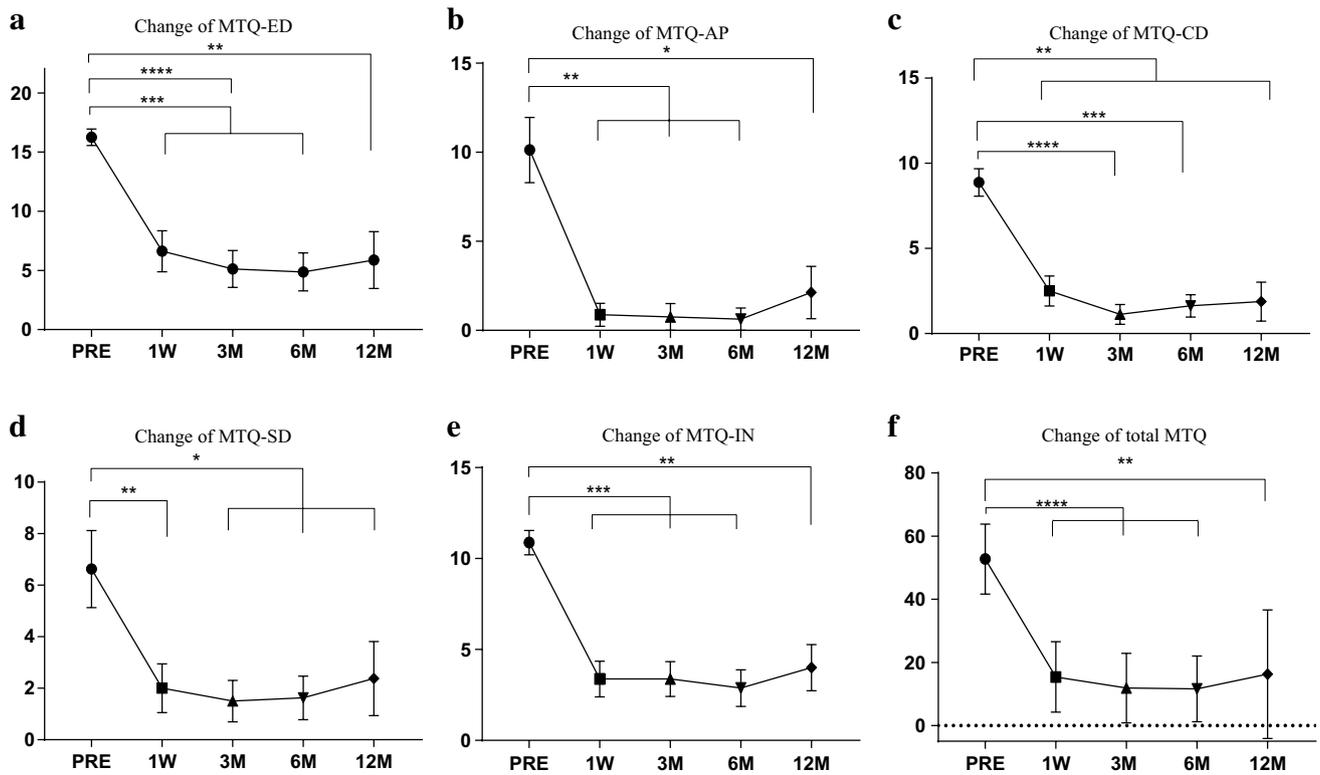


Fig. 2 Preoperative and postoperative mandarin tinnitus questionnaire (MTQ) scores. The MTQ scores including emotional distress (ED, **a**), auditory perceptual difficulties (AP, **b**), cognitive distress (CD, **c**), sleep disturbance (SD, **d**), intrusiveness (IN, **e**) and total MTQ (**f**) all significantly decreased at 1 week (1W), 3 months (3M), 6 months

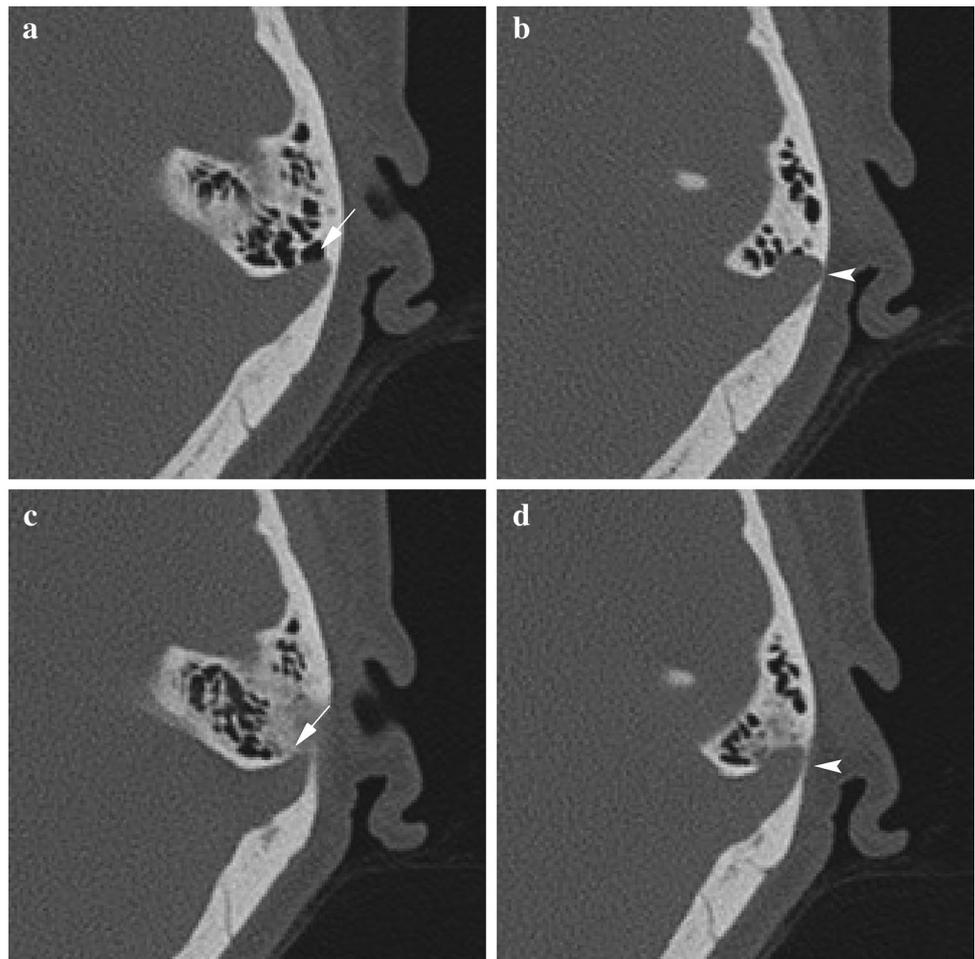
(6M) or 12 months (12M) after operation when compared to preoperative ones (PRE). There was no significant difference among different MTQ scores at different time after operation, respectively. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$

Conclusion

Our study suggests that sigmoid sinus bony wall repair is successful for significantly reducing both the physical and psychological impacts of PT due to SSWA. Sigmoid sinus bony wall

defects play a key role in the pathophysiology of PT due to SSWA. Restricting the turbulence of blood flow in the sigmoid sinus might not be necessary.

Fig. 3 Preoperative (**a** and **b**) and postoperative (**c** and **d**) CT findings of case 5. **a** Preoperative CT image showed the defect on sigmoid sinus bony wall (arrow). **b** Preoperative CT image showed the diverticulum at different location of the above-mentioned defect (arrowhead). **c** Postoperative CT image of the corresponding layer of image **a** showed that the defect of sigmoid sinus bony wall had been successfully repaired (arrow). **d** Postoperative CT image of the corresponding layer of image **b** showed that diverticulum still exist (arrowhead)



Compliance with ethical standards

Conflict of interest No conflict of interest exists in the submission of this manuscript.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

- Liyanage SH, Singh A, Savundra P, Kalan A (2006) Pulsatile tinnitus. *J Laryngol Otol* 120(2):93–97. <https://doi.org/10.1017/s0022215105001714>
- Holgate RC, Wortzman G, Noyek AM, Makerewicz L, Coates RM (1977) Pulsatile tinnitus: the role of angiography. *J Otolaryngol Suppl* 3:49–62
- Mattox DE, Hudgins P (2008) Algorithm for evaluation of pulsatile tinnitus. *Acta Otolaryngol* 128(4):427–431. <https://doi.org/10.1080/00016480701840106>
- Miller TR, Serulle Y, Gandhi D (2016) Arterial abnormalities leading to tinnitus. *Neuroimaging Clin N Am* 26(2):227–236. <https://doi.org/10.1016/j.nic.2015.12.002> (%/Copyright (c) 2016 Elsevier Inc. All rights reserved)
- Hofmann E, Behr R, Neumann-Haefelin T, Schwager K (2013) Pulsatile tinnitus: imaging and differential diagnosis. *Dtsch Arztebl Int* 110(26):451–458. <https://doi.org/10.3238/arztebl.2013.0451>
- Schoeff S, Nicholas B, Mukherjee S, Kesser BW (2014) Imaging prevalence of sigmoid sinus dehiscence among patients with and without pulsatile tinnitus. *Otolaryngol Head Neck Surg* 150(5):841–846. <https://doi.org/10.1177/0194599813520291>
- Otto KJ, Hudgins PA, Abdelkafy W, Mattox DE (2007) Sigmoid sinus diverticulum: a new surgical approach to the correction of pulsatile tinnitus. *Otology and neurotology: official publication of the American otological society. Am Neurotol Soc Eur Acad Otol Neurotol* 28(1):48–53. <https://doi.org/10.1097/01.mao.0000247814.85829.f6>
- Sanchez TG, Murao M, de Medeiros IR, Kii M, Bento RF, Caldas JG, Alvarez CA, Raggiotto CH (2002) A new therapeutic procedure for treatment of objective venous pulsatile tinnitus. *Int Tinnitus J* 8(1):54–57
- Eisenman DJ (2011) Sinus wall reconstruction for sigmoid sinus diverticulum and dehiscence: a standardized surgical procedure for a range of radiographic findings. *Otology and neurotology: official publication of the American Otolological Society. Am Neurotol Soc Eur Acad Otol Neurotol* 32(7):1116–1119. <https://doi.org/10.1097/MAO.0b013e31822a1c7d>
- Xue J, Li T, Sun X, Liu Y (2012) Focal defect of mastoid bone shell in the region of the transverse-sigmoid junction: a new cause

- of pulsatile tinnitus. *J Laryngol Otol* 126(4):409–413. <https://doi.org/10.1017/s0022215111003458>
11. Wang GP, Zeng R, Liu ZH, Liang XH, Xian JF, Wang ZC, Gong SS (2014) Clinical characteristics of pulsatile tinnitus caused by sigmoid sinus diverticulum and wall dehiscence: a study of 54 patients. *Acta Otolaryngol* 134(1):7–13. <https://doi.org/10.3109/00016489.2013.831479>
 12. Harvey RS, Hertzano R, Kelman SE, Eisenman DJ (2014) Pulse-synchronous tinnitus and sigmoid sinus wall anomalies: descriptive epidemiology and the idiopathic intracranial hypertension patient population. *Otology & neurotology: official publication of the American otological society. Am Neurotol Soc Eur Acad Otol Neurotol* 35(1):7–15. <https://doi.org/10.1097/MAO.0b013e3182a4756c>
 13. Zeng R, Wang GP, Liu ZH, Liang XH, Zhao PF, Wang ZC, Gong SS (2016) Sigmoid sinus wall reconstruction for pulsatile tinnitus caused by sigmoid sinus wall dehiscence: a single-center experience. *PLoS One* 11(10):e0164728. <https://doi.org/10.1371/journal.pone.0164728>
 14. Song JJ, Kim YJ, Kim SY, An YS, Kim K, Lee SY, Koo JW (2015) Sinus wall resurfacing for patients with temporal bone venous sinus diverticulum and ipsilateral pulsatile tinnitus. *Neurosurgery* 77(5):709–717. <https://doi.org/10.1227/NEU.0000000000000902> (discussion 717).
 15. Friedmann DR, Eubig J, McGill M, Babb JS, Pramanik BK, Lalwani AK (2011) Development of the jugular bulb: a radiologic study. *Otology and neurotology: official publication of the American otological society. Am Neurotol Soc Eur Acad Otol Neurotol* 32(8):1389–1395. <https://doi.org/10.1097/MAO.0b013e31822e5b8d>
 16. Wang GP, Zeng R, Ma XB, Liu ZH, Wang ZC, Gong SS (2015) Surgical treatment of pulsatile tinnitus caused by the sigmoid sinus diverticulum: a preliminary study. *Medicine (Baltimore)* 94(21):e882. <https://doi.org/10.1097/md.0000000000000882>
 17. Guo P, Wang WQ (2015) Degree of sigmoid sinus compression and the symptom relief using magnetic resonance angiography in venous pulsating tinnitus. *Clin Exp Otorhinolaryngol* 8(2):111–116. <https://doi.org/10.3342/ceo.2015.8.2.111>
 18. Wee JH, Song JJ, Koo JW, Kim CS (2012) Increased intracranial pressure after surgical treatment of pulsatile tinnitus from a prominent sigmoid sinus. *Otol Neurotol* 33(6):e41–42. <https://doi.org/10.1097/MAO.0b013e318245cb22>
 19. Giuseffi V, Wall M, Siegel PZ, Rojas PB (1991) Symptoms and disease associations in idiopathic intracranial hypertension (pseudotumor cerebri): a case-control study. *Neurology* 41(2 Pt 1):239–244
 20. Houdart E, Chapot R, Merland JJ (2000) Aneurysm of a dural sigmoid sinus: a novel vascular cause of pulsatile tinnitus. *Ann Neurol* 48(4):669–671
 21. Sismanis A (1998) Pulsatile tinnitus. A 15-year experience. *Am J Otol* 19(4):472–477
 22. Paramasivam S, Furtado S, Shigamatsu T, Smouha E (2016) Endovascular management of sigmoid sinus diverticulum. *Interv Neurol* 5(1–2):76–80. <https://doi.org/10.1159/000444507>
 23. Li B, Lv X, Wu Z, Cao X, Wang J, Ge A, Liu X, Li S (2016) Stent-assisted coil embolization of a transverse-sigmoid sinus diverticulum presenting with pulsatile tinnitus. *Turk Neurosurg* 26(4):632–634. <https://doi.org/10.5137/1019-5149.jtn.8140-13.3>
 24. Santos-Franco JA, Lee A, Nava-Salgado G, Zenteno M, Vega-Montesinos S, Pane-Pianese C (2012) Hybrid carotid stent for the management of a venous aneurysm of the sigmoid sinus treated by sole stenting. *Vasc Endovascular Surg* 46(4):342–346. <https://doi.org/10.1177/1538574412442593>
 25. Gologorsky Y, Meyer SA, Post AF, Winn HR, Patel AB, Bederson JB (2009) Novel surgical treatment of a transverse-sigmoid sinus aneurysm presenting as pulsatile tinnitus: technical case report. *Neurosurgery* 64(2):E393–E394. <https://doi.org/10.1227/01.neu.0000338255.93266.00> (discussion E394).
 26. Park JH, Noh TS, Lee JH, Oh SH, Kim JS, Chung CK, Suh MW (2015) Difference in Tinnitus Treatment Outcome According to the Pulse Number of Repetitive Transcranial Magnetic Stimulation. *Otol Neurotol* 36(8):1450–1456. <https://doi.org/10.1097/mao.0000000000000802>
 27. Kim DK, Park SN, Kim MJ, Lee SY, Park KH, Yeo SW (2011) Tinnitus in patients with chronic otitis media before and after middle ear surgery. *Eur Arch Otorhinolaryngol* 268(10):1443–1448. <https://doi.org/10.1007/s00405-011-1519-9>
 28. Meng Z, Chen Z, Xu K, Li G, Tao Y, Kwong JS (2016) Psychometric properties of a Mandarin version of the tinnitus questionnaire. *Int J Audiol* 55(6):366–374. <https://doi.org/10.3109/14992027.2016.1146414>
 29. Wang AC, Nelson AN, Pino C, Svider PF, Hong RS, Chan E (2017) Management of sigmoid sinus associated pulsatile tinnitus: a systematic review of the literature. *Otol Neurotol* 38(10):1390–1396. <https://doi.org/10.1097/MAO.0000000000001612>
 30. Navsa N, Kramer B (1998) A quantitative assessment of the jugular foramen. *Ann Anat* 180(3):269–273. [https://doi.org/10.1016/s0940-9602\(98\)80086-1](https://doi.org/10.1016/s0940-9602(98)80086-1)
 31. Kim CS, Kim SY, Choi H, Koo JW, Yoo SY, An GS, Lee K, Choi I, Song JJ (2016) Transmastoid reshaping of the sigmoid sinus: preliminary study of a novel surgical method to quiet pulsatile tinnitus of an unrecognized vascular origin. *J Neurosurg* 125(2):441–449. <https://doi.org/10.3171/2015.6.JNS15961>
 32. Eisenman DJ, Raghavan P, Hertzano R, Morales R (2018) Evaluation and treatment of pulsatile tinnitus associated with sigmoid sinus wall anomalies. *The Laryngoscope* 128(Suppl 2):S1–S13. <https://doi.org/10.1002/lary.27218>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.