

Long-Term Hearing Outcome After Retrosigmoid Removal of Vestibular Schwannoma

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Abstract

Although many investigators have reported the hearing function in the immediate postoperative period in patients with vestibular schwannoma (VS), little is known about the long-term outcomes of the postoperative hearing. The aim of this study was to analyze the long-term hearing outcomes at a mean follow-up of 5 years in patients with unilateral VS treated via the retrosigmoid approach. Twenty-four patients with immediate postoperative serviceable hearing who underwent repeated audiogram or phone interview were included in this study. During the mean follow-up period (68.8 ± 30.2 months, range 14–123 months), serviceable hearing was preserved in 20 out of the 24 patients (83%). Pure tone average (PTA) was reevaluated within 6 months in seven patients. In the two patients whose PTA deteriorated ≥ 5 dB in 6 months after surgery, their PTA worsened ≥ 15 dB compared to the immediate postoperative PTA. In the remaining five patients whose PTA deteriorated < 5 dB in 6 months after surgery, PTA was maintained within a 15-dB deterioration at the final follow-up ($p = 0.04$, Fisher's exact test). According to Kaplan–Meier survival plots, the 5-year or 7-year preservation rate of serviceable hearing was 86.2% or 71.8%, respectively. Further study will be needed to clarify the mechanism underlying the long-term decline of serviceable hearing; however, the deterioration of PTA in the early postoperative period may help to predict the long-term outcomes of hearing.

Key words: long-term outcome, hearing, vestibular schwannoma, acoustic neuroma, retrosigmoid approach

Introduction

Although many studies offering descriptions of the rate of hearing preservation in the immediate postoperative period after vestibular schwannoma (VS) surgery have been published,^{6,9,15,24–26} neurosurgeons tend to overlook the long-term outcomes of the preserved serviceable hearing. Several authors have assessed the changes of postoperative hearing function^{2,3,7,11,13,14,16,21,27,31,32}, however, the follow-up periods were shorter than 5 years in most studies. A vast majority of studies have been reported from the Otolaryngology department. In those reports, the mean size of the tumors was small and the detailed information that might influence the hearing outcome was not discussed.^{2,7,13,16,21,23,27,31} The aim of this study was to analyze the long-term outcomes of serviceable hearing after retrosigmoid removal in the patients with unilateral VS at a mean follow-up of 5 years and to attempt to find the predictive factors

for the successful long-term hearing preservation.

Patients and Methods

Between 2002 and 2011, the senior author (Tomio Sasaki) performed surgery in 114 patients with unilateral VS via a retrosigmoid, lateral suboccipital approach at our institution.²⁶ Written informed consent was obtained from all patients. Patients with bilateral acoustic tumors (neurofibromatosis Type 2) were excluded from this study. In all patients, pure tone average (PTA) and speech discrimination score (SDS) were evaluated by audiologists, and 57 patients had retained useful hearing on the tumor side preoperatively (defined as PTA ≤ 50 dB and SDS $\geq 50\%$; Gardner–Robertson [GR] Classifications I and II).⁸ The waveform of preoperative auditory brainstem response (ABR) was divided into four groups: intact morphology, normal ABR waveform with delayed V wave latency (V delay), only I wave, and no response. There were no pure intracanalicular tumors in our cases, and the volume of the tumor

in the cerebellopontine cistern was measured in all cases on preoperative magnetic resonance (MR) images. Tumor characteristics were divided into solid, cystic, or necrotic based on preoperative MR imaging and intraoperative findings. The extent of tumor removal was evaluated by postoperative MR images as described previously.^{18,26} Intraoperative appearances of the eighth cranial nerve were divided into fanning and bundle. Postoperative serviceable hearing was defined by assessments of PTA and SDS (i.e., GR Classifications I and II). Twenty-eight out of 57 patients retained serviceable hearing postoperatively. An effort was made to acquire audiograms of patients without recent audiologic data. Letters and informed consents were mailed to the patients requesting a recent audiogram. Four of 28 patients were lost to follow-up, and 24 patients were included in this study. There was no difference in patients' characteristics between the included and excluded patients. Five patients did not agree to undergo audiogram; however, they accepted to give interviews by phone. For them, hearing was defined as serviceable in cases in which they could hear the voice and converse using the operated ear. Nineteen out of 28 patients with postoperative serviceable hearing underwent repeated audiogram longer than 1 year. Because SDS was not routinely conducted at all intervals, the serviceable hearing during the follow-up period was defined as PTA \leq 50 dB. Significant hearing loss was considered to be an increase in PTA of 15 dB compared to PTA at immediate postoperative period according to the criteria of Thornton and Raffin.³⁰

There were 8 men and 16 women with a mean age of 45.2 ± 11.1 years (range 22–62 years) at the operations (Table 1). Age was not an exclusion criterion; however, there was no patient older than 65 years in this analysis because we took a wait-and-see approach for the aged patients who harbored small VSs. There were 12 right-sided lesions and 12 left-sided lesions. The mean volume of the tumor was 4.5 ± 8.1 cm³ ranging from 0.1 cm³ to 35.0 cm³. Total or near-total resection was achieved in 21 tumors and subtotal resection in 3. In cases in which the internal auditory canal (IAC) was opened, posterior wall of the IAC was packed with fat, oxidized cellulose cotton, and fibrin glue. Care was taken to maintain sufficient space between the eighth cranial nerve and fat in order to make nothing adhere to the eighth cranial nerve. The mean follow-up period for audiometry or phone interview was 68.8 ± 30.2 months (\pm SD, range 14–123 months). Among all the patients, recurrent tumors were not found by MR images during the follow-up period.

Commercially available software (JMP version 9; SAS Institute, Cary, North Carolina, USA) was used for statistical analysis. Multiple regression analysis was performed to study predictors for the long-term hearing outcomes. The significance was indicated by a value of $p < 0.05$. Wilcoxon rank test was utilized for nonparametric comparison, and the hearing preservation rates were established using the Kaplan–Meier product-limit method. Prism version 5.0 software (GraphPad Software, Inc., San Diego, California, USA) was used for Fisher's exact test.

Results

Individual sequential audiometry plotting of 19 patients is summarized in Fig. 1. In most patients, PTA of the operated ear deteriorated immediately after surgery, and then it was unchanged or slightly deteriorated (Fig. 1A). In contrast, PTA of the contralateral ear was maintained during the follow-up; PTA was less than 30 dB in 17 out of 19 patients and 33.8 dB or 60.0 dB in 2 whose immediate postoperative PTA was already 31.7 dB or 73.3 dB, respectively (Fig. 1B). Interestingly, PTA of the contralateral ear deteriorated transiently immediately after surgery in 6 of 19 patients, and it improved in five cases during the follow-up. PTA of the operated ear remained unchanged or within a \leq 15-dB deterioration (hearing preserved) in 13 patients during the follow-up period (Fig. 2A), whereas it deteriorated $>$ 15 dB (significant hearing loss) in six (Fig. 2B). PTA was reevaluated within 6 months in seven patients. In the two patients whose PTA deteriorated \geq 5 dB in 6 months after surgery, their PTA worsened \geq 15 dB compared to the immediate postoperative PTA. In the remaining five patients whose PTA deteriorated $<$ 5 dB in 6 months after surgery, PTA was maintained within a 15-dB deterioration at the final follow-up ($p = 0.04$, Fisher's exact test). Serviceable hearing was preserved in 20 of the 24 patients (83%) during the follow-up period (Table 1). In one patient whose preoperative and immediate postoperative PTAs were 44.2 dB and 45.0 dB, respectively, hearing declined to the nonserviceable level at 54 months after surgery despite her PTA deteriorated only 7.5 dB (Case 17 in Table 1).

According to Kaplan–Meier survival plots, the 5-year or 7-year preservation rate of serviceable hearing in 19 patients who underwent repeated PTA was 86.2% or 71.8%, respectively (Fig. 3A). The 5-year or 7-year provability without significant hearing loss (defined as remained unchanged or within a \leq 15-dB deterioration of PTA according to the criteria of Thornton and Raffin) was 82.6%

Table 1 Characteristics of 24 patients with serviceable hearing immediately after surgery for vestibular schwannoma

Case No.	Age/sex	Tumor side	Tumor volume (cm ³)	Preoperative hearing status			Preoperative waveform of ABR	Tumor consistency	Extent of tumor removal	Intraoperative finding of VIII	IAC opening	Immediate postoperative hearing status			PTA at final F/U (dB)	Final F/U (m)
				PTA (dB)	SDS (%)	GR class						PTA (dB)	SDS (%)	GR class		
1	22/F	L	15.5	7.5	100	1	V wave delay	Cystic	Subtotal	Bundle	Yes	16.7	N/A	1	16.7	34
2	43/F	L	0.1	12.5	100	1	Intact	Solid	Total	Bundle	Yes	13.3	100	1	18.3	121
3	34/F	L	0.6	6.7	100	1	Intact	Solid	Total	Fanning	Yes	11.7	N/A	1	30.0	70
4	36/F	R	0.3	13.3	100	1	V wave delay	Solid	Total	Bundle	Yes	17.5	100	1	31.3	40
5	45/M	L	1.1	21.7	100	1	V wave delay	Solid	Total	Bundle	Yes	28.8	95	1	33.3	52
6	50/M	L	0.1	26.7	90	1	V wave delay	Solid	Total	Bundle	Yes	35.0	95	2	35.0	71
7	34/F	R	6.5	21.7	85	1	Only I wave	Solid	Total	Fanning	Yes	31.7	60	2	37.5	27
8	32/F	L	35.0	15.0	90	1	Only I wave	Cystic	Subtotal	Bundle	No	15.0	90	1	37.8	93
9	60/M	R	0.1	40.0	70	2	V wave delay	Solid	Subtotal	Fanning	Yes	41.7	75	2	38.3	63
10	52/F	L	1.3	13.3	100	1	V wave delay	Solid	Near-total	Fanning	Yes	20.0	100	1	38.3	76
11	35/F	R	3.2	48.3	70	2	V wave delay	Solid	Near-total	Fanning	Yes	38.3	85	2	38.8	95
12	35/F	R	5.4	16.7	100	1	V wave delay	Solid	Near-total	Fanning	Yes	15.8	100	1	43.7	104
13	60/M	L	8.2	25.0	100	1	V wave delay	Cystic	Total	Bundle	Yes	41.7	90	2	43.8	33
14	48/F	R	0.6	36.7	80	2	V wave delay	Solid	Total	Fanning	No	36.7	95	2	45.0	55
15	51/M	L	1.9	30.0	100	1	Only I wave	Cystic	Total	Fanning	Yes	36.7	95	2	45.0	75
16	57/F	L	4.8	38.3	90	2	No response	Necrotic	Near-total	Fanning	Yes	48.3	90	2	48.3	93
17	44/F	L	2.9	44.2	90	2	V wave delay	Cystic	Total	Fanning	Yes	45.0	90	2	52.5	54
18	42/F	R	0.1	33.3	85	2	V wave delay	Solid	Total	Bundle	Yes	31.7	90	2	55.0	52
19	59/F	R	1.0	25.0	100	1	V wave delay	Solid	Total	Bundle	Yes	30.0	N/A	1	65.0	77
20	56/F	R	0.5	20.0	100	1	V wave delay	Solid	Total	Fanning	Yes	31.7	90	2	Useful on phone	14
21	62/M	L	0.3	34.2	90	2	Intact	Solid	Total	Bundle	Yes	38.3	90	2	Useful on phone	59
22	29/F	R	0.1	16.7	100	1	V wave delay	Solid	Total	Bundle	Yes	26.7	100	1	Useful on phone	120
23	47/M	R	1.0	20.0	100	1	V wave delay	Solid	Near-total	Fanning	Yes	23.3	95	1	Useful on phone	123
24	51/M	R	18.1	23.3	95	1	V wave delay	Cystic	Near-total	Bundle	Yes	33.3	100	2	Not useful on phone	51

ABR: auditory brainstem response, F/U: follow-up, GR class: Gardner–Robertson classification, IAC: internal auditory canal, PTA: pure tone average, SDS: speech discrimination score, VIII: the eighth cranial nerve.

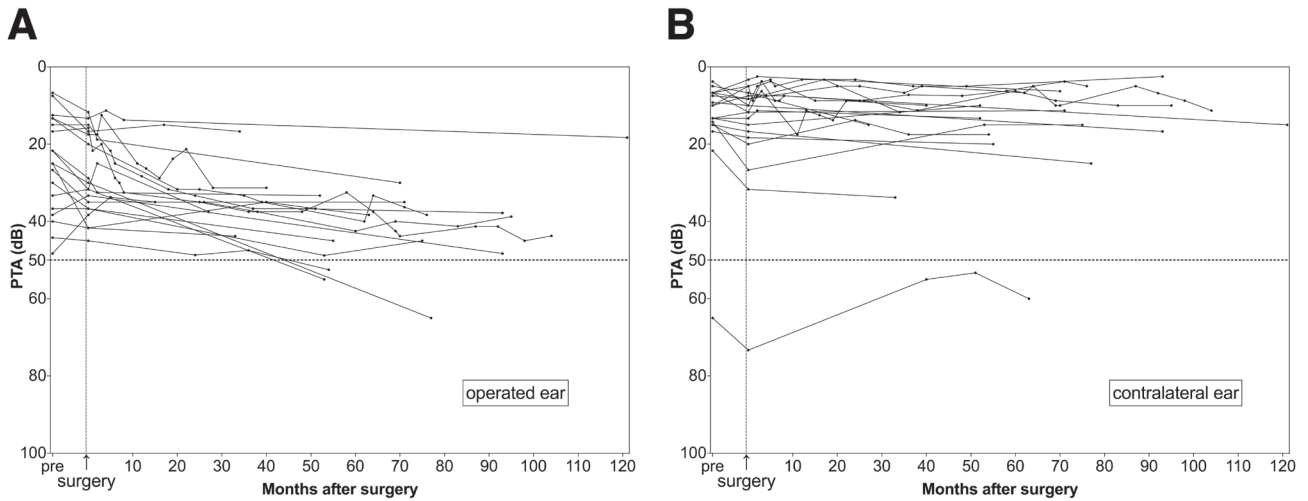


Fig. 1 Sequential plotting of pure tone average (PTA) changes in vestibular schwannoma patients treated with retrosigmoid removal. **A:** Operated ear. **B:** Contralateral ear. A vertical dotted line indicates the timing for a surgery. A horizontal dotted line shows PTA = 50 dB.

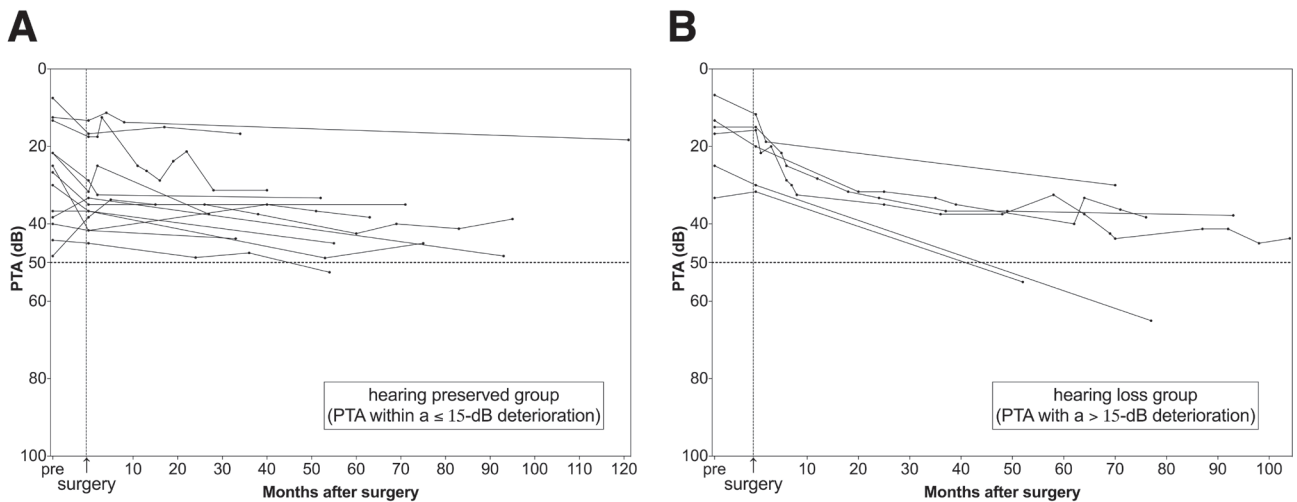


Fig. 2 Sequential plotting of pure tone average (PTA) changes of the operated ear in vestibular schwannoma patients treated with retrosigmoid removal. **A:** Patients with unchanged or remained PTA within a ≤ 15 -dB deterioration. **B:** Patients with PTA deteriorated > 15 dB. A vertical dotted line indicates the timing for a surgery. A horizontal dotted line shows PTA = 50 dB.

or 47.2%, respectively (Fig. 3B).

Patient age was not a predictor for the long-term preservation of hearing in multivariate analysis; however, patients older than 65 years were not included in this analysis. Other factors including sex, tumor volume, preoperative hearing status, the waveform of preoperative ABR, tumor characteristics, extent of tumor removal, intraoperative appearance of the eighth cranial nerve, opening of the IAC, and immediate postoperative hearing status also did not

correlate with the long-term preservation of hearing in multivariate analysis.

Discussion

We showed that the long-term preservation of serviceable hearing was achieved in 83% of patients with immediate postoperative serviceable hearing after removal of VS via retrosigmoid approach at a mean follow-up of 5 years. Six of 19 patients experienced

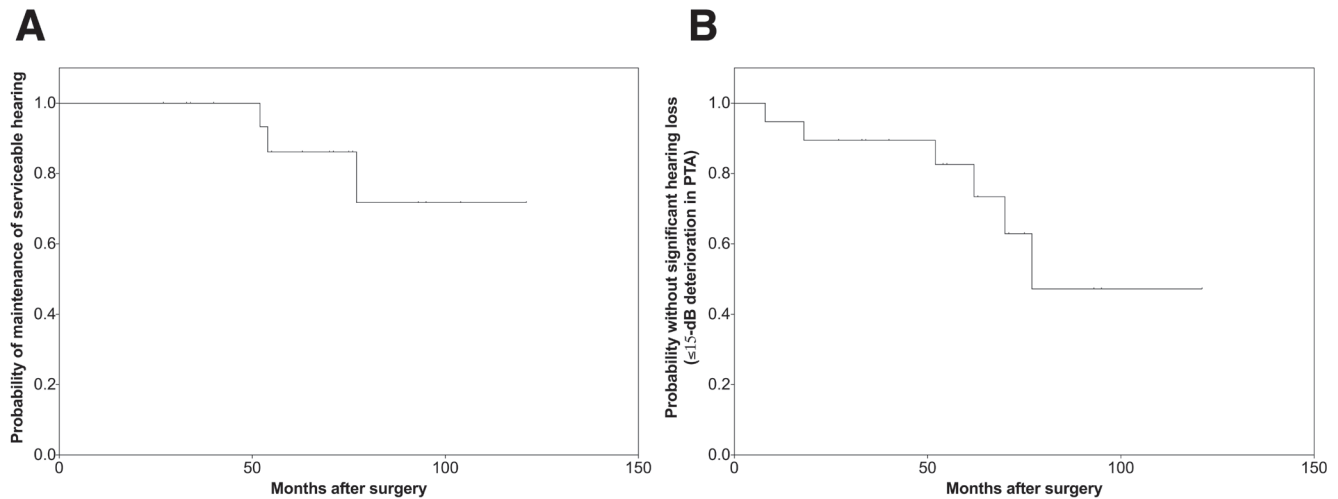


Fig. 3 Kaplan–Meier survival plot of hearing preservation in vestibular schwannoma patients treated with retrosigmoid removal. **A:** Probability of maintenance of serviceable hearing. **B:** Probability without significant hearing loss, i.e., deterioration of pure tone average (PTA) within 15 dB.

transient hearing decline of the contralateral ear immediately after surgery; however, little is known about the postoperative changes in the hearing of the contralateral ear. Intraoperative loss of cerebrospinal fluid and brain shift could play a role in this condition. The information on the possibility of a postoperative transient decline in hearing function of the contralateral ear should be provided to all patients preoperatively.

The reported rates of hearing decline after VS surgery varied in range from 0% to 56%.^{2,3,7,11,13,14,16,21,23,27,31,32} This variability is thought to be mainly due to the difference in the definition of hearing preservation, in the length of the follow-up, or in the surgical approaches. It is difficult to analyze the reported results of hearing preservation because there is no agreement as to what constituted “hearing.” Some authors considered deterioration of any hearing a decline,^{2,3,11,14,21,23} whereas others used specific audiometric parameters such as GR class^{7,13} or the criteria of Thornton and Raffin^{16,27,31,32} to define a decline of hearing. Several authors reported that the incidence of a decline in hearing quality tended to become higher the longer the postoperative follow-up.^{2,13,16,27} A long and consecutive follow-up is required to elucidate the “long-term” hearing outcomes because sequential PTA plotting and Kaplan–Meier plotting in our and other’s study clearly demonstrated that PTA deteriorated gradually over time¹³; however, our results also demonstrated that deterioration of PTA in the early postoperative period may help to predict the long-term declines of hearing. In terms of surgical approach, there seemed to be no

difference in the rate of hearing decline between middle fossa approach and retrosigmoid approach. The hearing decline rate has been reported to be 0–43% in patients treated via the retrosigmoid approach,^{2,11,14,16,21,23,31,32} whereas 25–56% in patients treated via the middle fossa approach.^{3,7,13}

The mechanisms of a long-term decline of hearing and its prognostic factors remain unclear. As possible mechanisms, microscopic tumor recurrence,^{19,33,34} histopathological changes in the cochlea,^{27,32} endolymphatic hydrops,⁵ and the usage of muscle for packing the IAC were proposed.²⁷ Shelton et al.²⁷ reported that histopathological changes in the cochlea could be reduced by an usage of abdominal fat instead of temporal muscle. Inoue et al.¹³ demonstrated that there was no difference in the course of hearing deterioration between the usage of abdominal fat (n = 12) and temporal muscle (n = 8). Fat could cause a hearing decline; however, we avoided the direct contact of fat with the eighth cranial nerve in all cases. Several authors have demonstrated no correlation between a long-term hearing outcome and tumor volume, preoperative hearing quality, patient age, or symptoms.^{3,16,31} In our study, we analyzed another factors including patient sex, the waveform of preoperative ABR, tumor constituency, extent of tumor removal, intraoperative appearance of the eighth cranial nerve, opening of the IAC, and immediate postoperative hearing status; however, we could not find the predictive factor for the long-term outcomes of serviceable hearing perhaps because of the limited number of our cases. More cases will be needed to clarify the factors related

to the hearing outcome.

Long-term outcomes of hearing after conservative treatment in patients with VS have been reported to be poor. Godefroy et al.¹⁰⁾ reported that hearing was preserved after conservative treatment in 57% of patients whose hearing was useful at diagnosis during a mean follow-up of 2 years. Stangerup et al.²⁸⁾ reported that only 41% of patients preserved good hearing after a mean follow-up of 4.7 years, and only 38% of the patients with only a small speech discrimination loss at diagnosis maintained good hearing during “wait and scan” management. Radiosurgery is a viable treatment modality for patients with VS and has the potential for hearing preservation^{12,29)}; however, Murphy et al.¹⁷⁾ and Arthurs et al.¹⁾ asserted the importance of long-term follow-up because hearing can continue to decline over time in the majority of patients after radiosurgery. Chopra et al.⁴⁾ reported that hearing preservation rate at 3 years after radiosurgery was 74%; however, it declined to 44.5% at 10 years. Similarly, Prasad et al.²²⁾ reported that no hearing deterioration was observed during the first 2 years of follow-up; however, hearing had subsequently declined and 62.5% of patients experienced worsening of hearing function at 8 years of follow-up. Paek et al.²⁰⁾ demonstrated that the 5-year serviceable hearing preservation rate of patients with serviceable hearing after gamma knife radiosurgery was 46%, and the 5-year hearing preservation rate (the rate remained at the same pre-gamma knife radiosurgery GR class) was 10%. Even though a limited number of our cases, retrosigmoid removal appeared not to be inferior to radiosurgery in hearing preservation.

Our study demonstrated the long-term outcomes of serviceable hearing in the patients with unilateral VS treated via the retrosigmoid removal. Further study will be needed to clarify the mechanism underlying the long-term decline of serviceable hearing; however, our results demonstrate that the deterioration of PTA in the early postoperative period may help to predict the long-term outcomes of hearing. Hearing of the patients whose PTA does not decline within 6 months after surgery will be expected to be maintained over an extended time period. Since some patients can experience transient hearing decline of the contralateral ear immediately after surgery, this information should be provided to all patients preoperatively.

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All the authors contributed to the work described in the article and all take responsibility for it.

Conflicts of Interest Disclosure

The authors have no conflict of interest and financial support in relation to this manuscript.

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