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Technical Notes & Surgical Techniques

Application of intraoperative ABR during middle ear surgery to predict improvement in hearing

Tianci Feng (MD)[a,b,1], Yuebo Chen (MD)[b,1], Hao Xiong (MD)[b], Yiqing Zheng (MD)[b,*], Haidi Yang (MD)[b,*]

[a] *Department of Hearing and Speech-Language Science, Xinhua College, Sun Yat-sen University, China*
[b] *Department of Otolaryngology, Sun Yat-sen Memorial Hospital, Sun Yat-sen University, China*

A R T I C L E I N F O

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A B S T R A C T

Objective: The present study was aimed to develop an intraoperative hearing monitoring method for surgeons to evaluate hearing improvement in the operating room under general anesthesia.
Method: Pure tone audiometry (PTA) and chirp auditory brainstem response (ABR) were evaluated for ears with normal hearing and conductive hearing loss before, immediately after, and 4 weeks after surgery.
Result: Our result showed that for ears with normal hearing or conductive hearing loss, preoperative chirp ABR threshold measured in the operating room under general anesthesia was highly linear correlated to 1000 Hz pure tone threshold and PTA threshold measured in the sound-proof chamber. Most interestingly, postoperative chirp ABR measured in the operating room under general anesthesia was also highly correlated with PTA threshold 1 month after surgery, which indicated that intraoperative chirp ABR can predict hearing improvement immediately after surgery.
Conclusion: Our findings demonstrate an effective intraoperative intervention to assess hearing improvement under general anesthesia in real time which might help avoid revision surgery.

1. Introduction

Middle ear diseases, including chronic suppurative otitis media, secretory otitis media, tympanosclerosis, otosclerosis, and cholesteanoma, would lead to conductive hearing loss that affects millions of people worldwide. Improving hearing in these patients is one of the most important purposes when treating these diseases. With the advance of surgical instruments and technique in recent years, hearing could be improved in most patients with middle ear diseases after middle ear surgery. However, as hearing can only be assessed by pure tone audiometry (PTA) after operation, surgeons could not tell patients how much their hearing was improved right after the operation and risk of revision surgery are still problems facing surgeons. With intraoperative hearing monitoring, more real time information can be provided to surgeons and surgery success rate could be probably increased, especially for junior surgeons.

To solve this problem, various methods had been used for intraoperative hearing monitoring. Wazen and colleagues firstly reported that electrocochleogram (ECochG) was an effective tool for assessing the efficacy of ossicular reconstruction in stapedectomies under general anesthesia [1,2]. However, as EcochG was recorded with electrode placed over the round window, the tympanic membrane and tympanomeatal flap remained uncovered throughout the assessing process, which should lower the assessing accuracy. Whisper hearing test was also used in stapedotomy under local anesthesia for hearing monitoring. But its efficacy was reported to be largely affected by subjective factors [3]. In addition, local anesthesia also limited its application.

Comparing to these two methods, intra-operating auditory brainstem response (ABR) was a less invasive and more objective method for hearing monitoring. It was first applied for intraoperative hearing monitoring in acoustic neuroma surgery [4]. Selesnick et al. suggested that intraoperative ABR may estimate the outcomes of surgery in conductive hearing loss cases [5]. Hsu reported that click ABR via earphones during stapedectomy could improve operative prognosis and reduce revision surgery rate [6]. Most recently, Wei and colleagues reported that intra-operating ABR using tone pip of 1 kHz via loudspeaker was an effective way to intraoperatively assess the hearing threshold in operating room under general anesthesia [7]. They

* Corresponding authors at: Department of Otolaryngology, SunYat-Sen Memorial Hospital of Sun Yat-Sen University, No. 107, Yuanjiang West Road, Guangzhou 510120, China.
E-mail addresses: zhengyiq@mail.sysu.edu.cn (Y. Zheng), yanghd@mail.sysu.edu.cn (H. Yang).
[1] Tianci Feng and Yuebo Chen contribute equally to this work.

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Table 1
Basic information of participants.

		Patient group	Control group
Sex	Male	11	11
	Female	16	4
Ear assessed	Left	13	7
	Right	14	8
Diagnosis	Middle ear cholesteatoma	6	
	Tympanosclerosis	3	
	Otosclerosis	5	
	Secretory otitis media	7	
	Chronic suppurative otitis media	6	
Operation	Tympanoplasty	15	
	Tympanostomy tube insertions	7	
	Stapedectomy with stapes piston prosthesis implantation	5	

compared hearing threshold obtained by PTA and tone pip ABR under general anesthesia in the operation room. The results showed that the two methods had a high correlation in assessing hearing threshold under such condition [7]. However, the study did not provide follow-up data. Moreover, only tone pip of 1 kHz was used in their study which was not enough to give comprehensive information about the hearing condition of patients.

Therefore, the current study attempted to use intraoperative chirp ABR to assess hearing threshold in patients with middle ear diseases before and immediately after middle ear surgery. Moreover, we also compared the hearing results obtained by chirp ABR and PTA during follow-up.

2. Method and material

2.1. Subject

Fifteen normal hearing ears (healthy side of 15 patients aged 28.8 ± 13.1 years who received middle ear operation on the other side) were set as control group. Twenty-seven ears of 27 patients aged 38.9 ± 11.10 years including 6 cases of middle ear cholesteatoma, 3 cases of tympanosclerosis, 5 cases of otosclerosis, 7 cases of secretory otitis media, and 6 cases of chronic suppurative otitis media were included in this study. Table 1 showed basic information of the 2 groups. Ethical approval was obtained from the Institutional Review Board of our hospital before the study began. Written consent was obtained from all participants before any of the study procedures were conducted.

2.2. Data collection

History was taken and necessary physical examination including otoscopy was performed before audiometric examination. Air conducted pure tone thresholds were obtained at frequencies from 250 to 8000 Hz using otometrics (Madsen Conera) in anechoic chamber. PTA threshold was defined as average threshold at 500, 1000, 2000 and 4000 Hz. Diagnosis was made by 2 ENT doctors of our center after necessary imaging test and oto-endoscopy, and respective operation was selected and done by the same ENT surgeon.

An intraoperative portable ABR test system (Neuro Audio, Ivanovo, Russia) was set up in the operation room. Loudspeaker was fixed 50 cm away from the central axis of the external auditory canal of the tested ear. White noise was delivered to the non-tested ear via an insert earphone for masking. ABR threshold using Chirp stimulus via a loudspeaker was attained in all participants under general anesthesia. Stimulus repetition rate was set to 27.1/s and superimposition 1024 times. The pre-amplifier was set to gain 100 k, with a bandpass filter of 300–1500 Hz. The recording electrode was placed in the forehead hairline with reference electrodes arranged in the left or right cheek respectively and the ground electrode in the nasion. The electrodes and the wires were covered by sterile surgical towels and intra-electrodes impedance was kept less than 4 kΩ.

Environmental noise in the operating room was kept lower than 42.5 dB. Signal intensity calibration was conducted using sound level meter (Norsonic, Lierskogen, Norway) set 50 cm from the speaker along its central axis. Deviation between values displayed in the test system screen and that of the sound level meter was < 5 dB. Dynamic range of the system output was set 47–75 dB SPL.

ABR threshold was defined as the presenting threshold of wave V. Initial intensity was set at 75 dB SPL. 10 dB step was used to found the wave V presenting threshold. The ABR threshold was determined according to the ABR Guidance by NHSP 2013, version 2.1. At each intensity, if three out of five waveforms showed a clear Wave V, then that intensity can be determined as 'response'.

All participants receive pure tone thresholds test before surgery and 1 month after surgery in a sound-proof chamber. For the control group, ABR measurements were only conducted before beginning of the surgery (preoperative ABR). For the patient group, ABR measurements were conducted twice: before operation and immediately after surgery (before packing, postoperative ABR).

2.3. Statistical analysis

Pure tone average (PTA) was calculated. Pearson correlation and linear regression analysis was applied between average PTA and ABR threshold as well as between 1000 Hz pure tone threshold and ABR threshold before operation for both groups. For patient group, difference of average PTA, 1000 Hz pure tone threshold and ABR threshold (DPTA, D1000 Hz and DABR) between before and after operation was calculated. Pearson correlation and linear regression analysis was applied for DPTA and DABR, D1000 Hz and DABR, PTA and ABR threshold after operation, and 1000 Hz pure tone threshold and ABR threshold after operation.

3. Result

Table 2 showed average PTA, 1000 Hz pure tone threshold and ABR thresholds of the 2 groups.

For control group, Pearson correlation showed that ABR threshold was significantly correlated to average PTA and 1000 Hz pure tone threshold ($r = 0.67$, $P = 0.006$ and $r = 0.76$, $P < 0.001$, respectively). Linear Regression analysis showed that both PTA threshold and 1000 Hz pure tone threshold had linear relations with the ABR threshold ($R2 = 0.45$, $R2 = 0.58$, respectively), as showed in Fig. 1.

Table 2
PTA, 1000 Hz and ABR thresholds result.

	Pre-operation			Post-operation		
	PTA	1000 Hz	ABR	PTA	1000 Hz	ABR
Patient group	48.7 ± 13.3	48.9 ± 15.1	58.5 ± 9.3	34.0 ± 13.4	31.3 ± 16.9	38.1 ± 13.0
Control group	11.3 ± 5.0	11.7 ± 6.2	13.7 ± 10.8			

All ABR threshold were attained under general anesthesia.

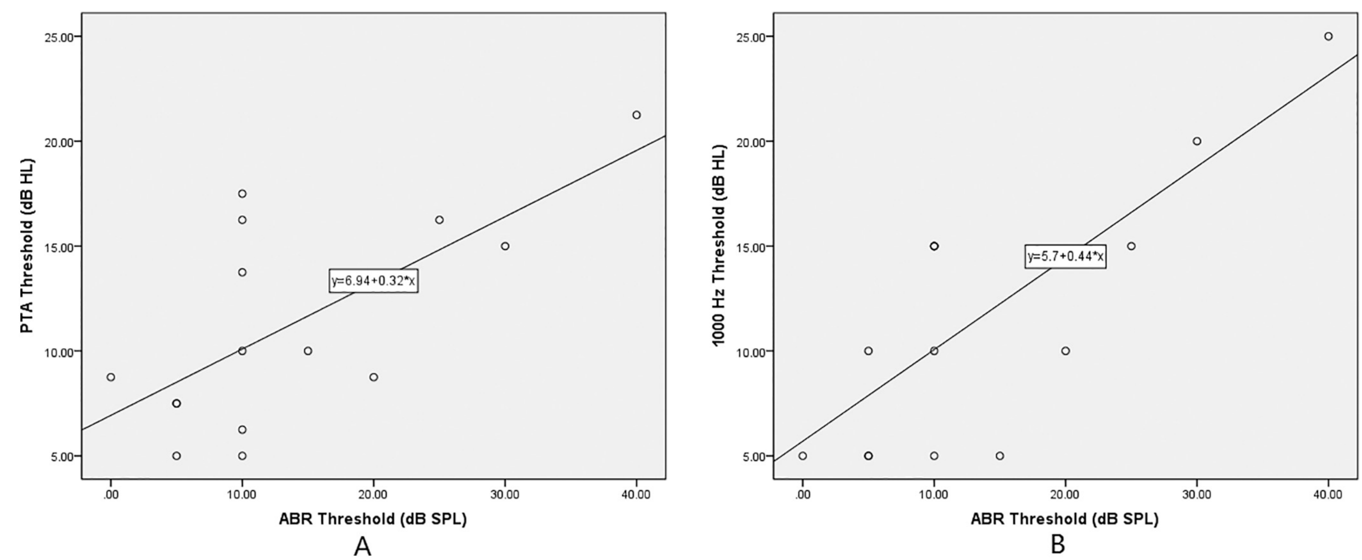

Fig. 1. A: Results of linear correlation analysis between the preoperative PTA and preoperative ABR threshold tested in control group. The Regression Equation was Y = 6.94 + 0.32X. Y represented PTA threshold (in dB SPL), and X represented ABR threshold (in dB HL). B: Results of linear correlation analysis between the preoperative 1000 Hz and preoperative ABR threshold tested in control group. The Regression Equation was Y = 5.7 + 0.44X. Y represented 1000 Hz threshold (in dB SPL), and X represented ABR threshold (in dB HL).

Table 3
Pearson correlation and linear regression result of patient group.

	Pre-operation		Post-operation		Difference	
	PTA and ABR	1000 Hz and ABR	PTA and ABR	1000 Hz and ABR	DPTA and DABR	D1000 Hz and DABR
r	0.55	0.46	0.68	0.62	0.40	0.43
P	0.003	0.012	< 0.001	0.001	0.041	0.024
R2	0.30	0.23	0.457	0.39	0.16	0.19
P	0.003	0.012	< 0.001	0.001	0.041	0.024

All ABR threshold were attained under general anesthesia.

For patient group, Pearson correlation and linear regression result were showed in Table 3 and Figs. 2–4. Significant linear correlation was attained between average PTA threshold and ABR threshold as well as between 1000 Hz pure tone threshold and ABR threshold in patient group preoperatively and postoperatively. Significant linear correlation was also attained between DPTA and DABR as well as between D1000 Hz and DABR.

4. Discussion

Conductive hearing loss resulting from middle ear disease affects millions of people around world. Although hearing could be improved to a certain extent with middle ear surgery in majority of patients, risk of revision surgery due to unsatisfying hearing improvement still exists. Many factors account for poor improvement of hearing after middle ear

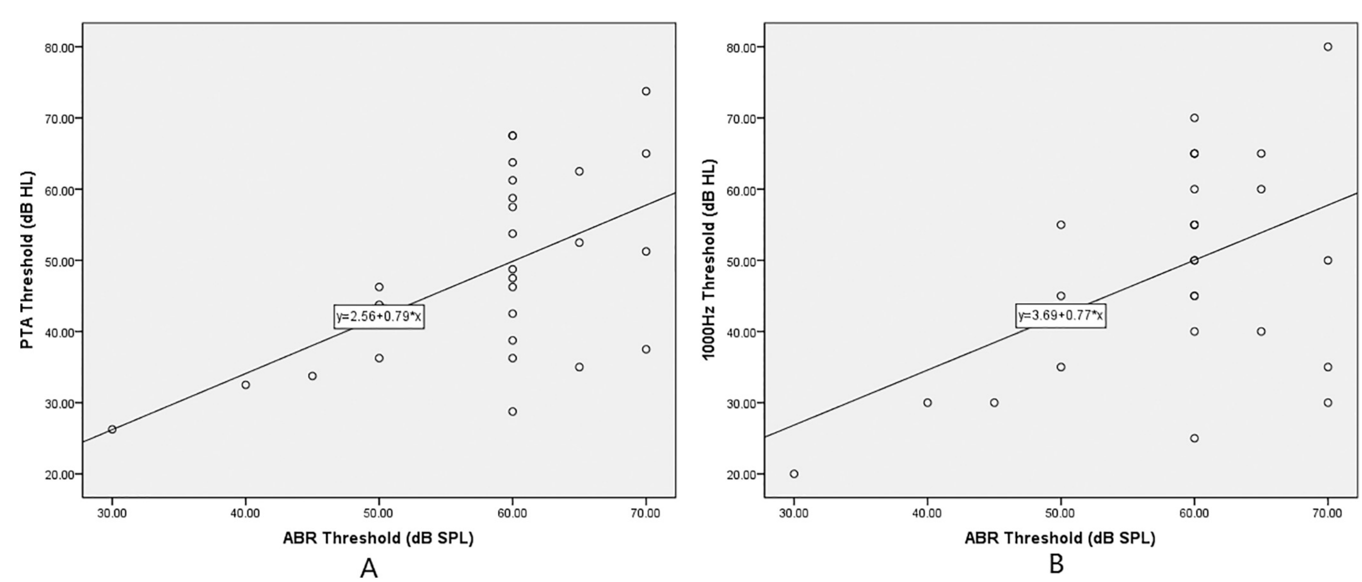

Fig. 2. A: Results of linear correlation analysis between the preoperative PTA and preoperative ABR threshold tested in patient group. The Regression Equation was Y = 2.56 + 0.79X. Y represented PTA threshold (in dB SPL), and X represented ABR threshold (in dB HL). B: Results of linear correlation analysis between the preoperative 1000 Hz and preoperative ABR threshold tested in patient group. The Regression Equation was Y = 3.69 + 0.77X. Y represented 1000 Hz threshold (in dB SPL), and X represented ABR threshold (in dB HL).

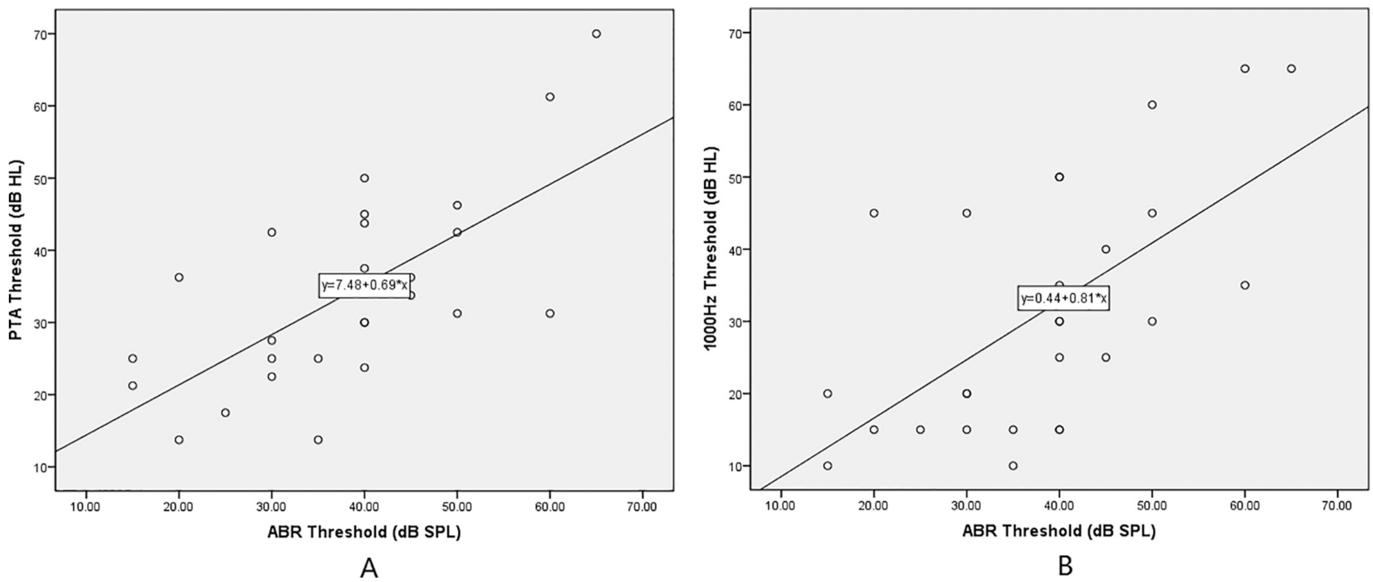

Fig. 3. A: Results of linear correlation analysis between the postoperative PTA and postoperative ABR threshold tested in patient group. The Regression Equation was Y = 7.48 + 0.69X. Y represented PTA threshold (in dB SPL), and X represented ABR threshold (in dB HL). B: Results of linear correlation analysis between the postoperative1000 Hz and postoperative ABR threshold tested in patient group. The Regression Equation was Y = 0.44 + 0.81X. Y represented 1000 Hz threshold (in dB SPL), and X represented ABR threshold (in dB HL).

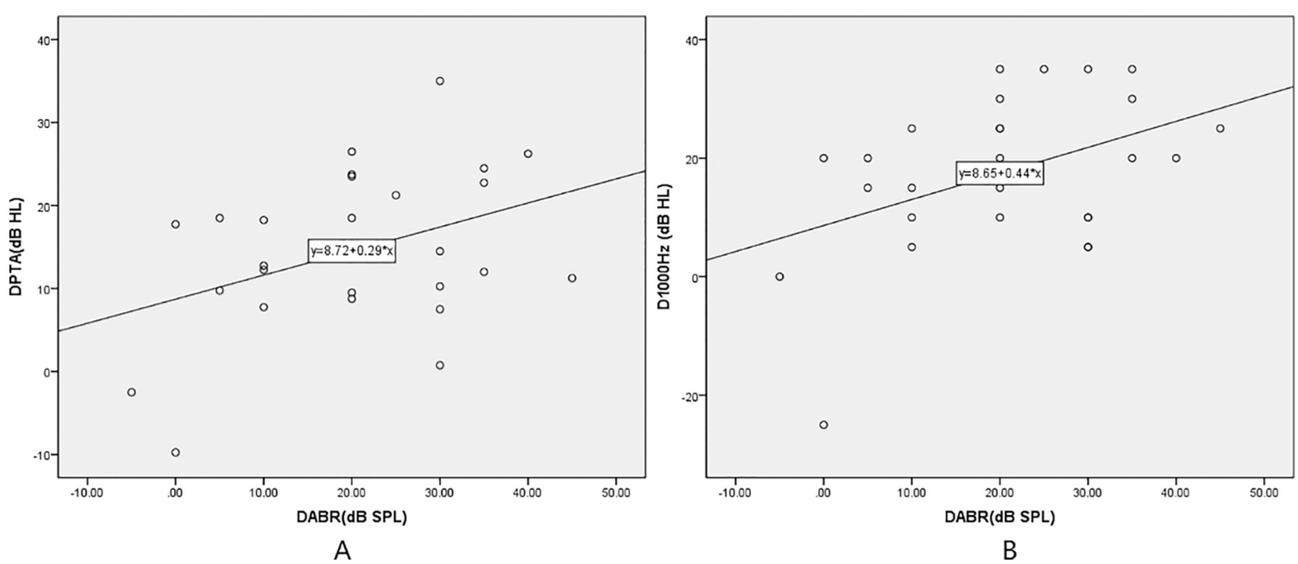

Fig. 4. A: Results of linear correlation analysis between DPTA and DABR tested in patient group. The Regression Equation was Y = 8.72 + 0.29X. Y represented DPTA (in dB SPL), and X represented DABR (in dB HL). B: Results of linear correlation analysis between D1000 Hz and DABR tested in patient group. The Regression Equation was Y = 8.65 + 0.44X. Y represented D1000 Hz (in dB SPL), and X represented DABR (in dB HL).

surgery, such as improper position of ossicular replacement prosthesis. Surgeons need more real time information about the effectiveness of ossicular replacement prosthesis during ossicular reconstruction surgery to improve surgery quality. Thus, it is important to develop an intraoperative hearing monitoring system to evaluate the immediate effect of the ossicular reconstruction and predict hearing improvement after surgery.

In the present study, we set up an intraoperative ABR monitoring system that can provide comprehensive information about the hearing level of patients before and immediately after middle ear operation. Our result showed that for both normal hearing ear and hearing-loss ear, preoperative ABR threshold was linear correlated to 1000 Hz pure tone threshold and PTA threshold, which was consisted with Ren's study [7]. However, in Ren's study, tone pip of 1 kHz was used as the stimulus in ABR measurement. ABR are historically recorded with a transient click that, due to their sudden start and broadband composition, supposedly activate synchronically a wide region of the cochlea. However, studies have shown that the response to the click is not totally synchronized. Considering the cochlear tonotopy, click sound always stimulates hair cells in the high frequency region at the basal cochlear turn earlier than low frequency region at the apical turn. For this reason, the hair cells are not stimulated at the same time, leading to an asynchronous depolarization of neurons. Because the low-frequency components provide delayed response peaks to be added to the response to high-frequency components, much information is lost in the overall response sum [8–11]. In addition, tone pip of single frequency stimulus used in Ren's study is apparently not sufficient for comprehensive assessment of hearing. Recently, a chirp stimulus has been developed which can compensate for basilar membrane traveling wave delay and increase synchronicity. The chirp stimulus shares the same frequency spectrum of a click but has a longer duration up to 10.33 ms. In this case, the chirp stimulus can stimulate all frequency regions of the cochlea at the same time. The advantages of chirp stimuli are as follows: 1. ABR amplitude is up to two times larger for chirp stimulation than click stimulation. Larger amplitude contributes to more confident identification of wave V and shorter test time to identify wave V. 2. Estimation range cover more frequency region in human speech [12–14]. Therefore, our results obtained by chirp stimulus provide more comprehensive information for hearing assessment.

Our date demonstrated intraoperative ABR threshold can be used to assess hearing level under general anesthesia. As we use 1000 Hz Chirp sound to attain ABR response, lower linear correction was attained between PTA threshold and ABR threshold. Different frequency sound should be used to gain more comprehensive information. Moreover, we also found that for conductive hearing loss ears, postoperative ABR threshold was still closely linear correlated to 1000 Hz pure tone threshold and PTA threshold 4 weeks postoperative. These findings indicate that postoperative ABR can predict patients' hearing improvement immediately after middle ear surgery in real time. Based on our results, surgeons can evaluate the effect of ossicular reconstruction surgery right after the surgery. In case the poor hearing improvement appeared, which indicated the ossicular replacement prosthesis may be not in its proper position, the revision can be processed immediately. These efforts could avoid second-look or revision surgery long time after middle ear surgery.

In summary, our study developed a reliable hearing monitoring system during the middle ear surgery. Our findings indicated that preoperative chirp ABR threshold under general anesthesia in the operating room was highly correlated with PTA threshold in patients. Most interestingly, postoperative chirp ABR measured in the operation room was also highly correlated with PTA threshold 1 month after surgery, which indicated intraoperative chirp ABR can predict hearing improvement immediately after surgery and might help avoid revision surgery.

Conflicts of interest and source of funding

The authors declare no conflicts of interest nor financial support.

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