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ScienceDirect

Journal of Otology 11 (2016) 178−184

www.journals.elsevier.com/journal-of-otology/

Review

Intra-operative hearing monitoring methods in middle ear surgeries

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Received 19 September 2016; revised 28 December 2016; accepted 28 December 2016

Abstract

Hearing loss is a condition affecting millions of people worldwide. Conductive hearing loss (CHL) is mainly caused by middle ear diseases. The low frequency area is the pivotal part of speech frequencies and most frequently impaired in patients with CHL. Among various treatments of CHL, middle ear surgery is efficient to improve hearing. However, variable success rates and possible needs for prolonged revision surgery still frustrate both surgeons and patients. Nowadays, increasing numbers of researchers explore various methods to monitor the efficacy of ossicular reconstruction intraoperatively, including electrocochleography (ECochG), auditory brainstem response (ABR), auditory steady state response (ASSR), distortion product otoacoustic emissions (DPOAE), subjective whisper test, and optical coherence tomography (OCT). Here, we illustrate several methods used clinically by reviewing the literature.

Keywords: Intraoperative monitoring; Middle ear surgery; Hearing

Contents

Hearing loss is a worldwide condition affecting millions of people. It can be divided into conductive hearing loss (CHL) and sensorineural hearing loss (SNHL) according to its pathogenic mechanisms. CHL is mainly caused by middle ear diseases. Low-frequencies, which are the pivotal part of speech frequencies, are the frequencies mostly impaired in patients with CHL. Therefore, middle ear diseases can greatly affect patients' communication and speech understanding.

Among various therapies for CHL, middle ear surgery may be the most effective in improving hearing. It has been

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Peer review under responsibility of PLA General Hospital Department of Otolaryngology Head and Neck Surgery.
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http://dx.doi.org/10.1016/j.joto.2016.12.003

reported that nearly 69% patients with CHL can gain improved hearing and reduced air-bone gap (ABG) via ear surgeries (Shah et al., 2013). As general anesthesia replaces local anesthesia in most otologic surgeries nowadays, it is difficult to assess efficacy of ossicular reconstruction intraoperatively. Therefore, the uncertainty in surgery success rate and possibility of needing revision surgeries continue to frustrate surgeons as well as patients.

Therefore, increasing numbers of researchers and surgeons are exploring ways to monitor hearing results during ossicular reconstruction operations, including electrocochleography (ECochG), auditory brainstem responses (ABRs), auditory steady state responses (ASSRs), distortion product otoacoustic emissions (DPOAEs), subjective whisper test, and optical coherence tomography (OCT).

1. Auditory brainstem responses (ABRs)

ABRs are a series of electrical potentials recorded from scalp electrodes upon acoustic stimulation, generated from auditory pathways, including the auditory nerve and brainstem (Moller et al., 1981; Moller and Jannetta, 1981) during the first 10–20 ms after the onset of a transient stimulus. They were firstly described by Jewett et al. (1970) and soon became the most widely used objective audiometry clinically for its objective, replicable, and noninvasive nature. ABRs are essentially unaffected by the patient's cognitive conditions, such as sleep, sedation or attention. They have been used to monitor auditory function during otological and neurotological procedures, and gradually become the routine intraoperative monitoring method in cerebellopontine angle surgeries and acoustic neuroma surgeries to alert the surgeon of an impending damage to the peripheral auditory pathway. Initially, ABRs were applied intraoperatively jointly with simultaneous ECochG (Lambert and Ruth, 1988), but since then both ABRs and ECochG have been treated as possible independent alternatives. Selesnick suggested that intraoperative brainstem auditory evoked responses (BAERs) monitoring might be able to predict postoperative hearing improvement in patients undergoing ossicular reconstruction surgery intraoperatively (Selesnick et al., 1997). Thereafter, more research has reported using ABRs as an intraoperative monitoring tool in middle ear surgeries, especially in stapes surgeries. Hsu monitored immediate hearing change during stapedectomy to guide adjustment of prosthesis positions, suggesting that intraoperative ABR monitoring might be a promising tool to help improve postoperative hearing outcomes and reduce the need for revision (Hsu, 2011).

Although intraoperative ABR monitoring can work smoothly in the operation room, it has its own limitations:

1. The above researches chose clicks as the stimulus signal. Clicks are broadband noise without frequency specificity, with its energy concentrating between 2 and 4 kHz. Folsom found that click-ABRs mainly reflected high frequency hearing thresholds with limited information on lower-frequency hearing both in adults and infants (Werner et al., 1993). Bauch et al. later also demonstrated that click-ABR thresholds correlated well with high frequency (2, 4 and 8 kHz) pure tone audiometry (PTA) results, rather than low frequencies (Stapells and Oates, 1997; Martinez Ibarguen, 1993). More and more reports point out that click-ABRs are better at predicting sensorineural rather than conductive hearing loss (Abdala and Folsom, 1995), which may affect its accuracy and predicting value in intraoperative hearing assessment in patients with CHL.
2. Although ABRs have been perceived as an "objective" measurement of hearing, subjective judgement is involved in identifying recorded waveforms and determining response threshold. Therefore a professionally trained surgeon or audiologist would be needed to interpret the results during middle ear surgeries. Nowadays automated ABRs (AABRs) have become a universal test in newborn hearing screening, but a few reports have suggested that AABRs can also be used as a standard test in adults. Further research is needed to study if AABRs during ossicular reconstruction surgeries can improve the accuracy of intra-operative monitoring.
3. Insert earphones are used as the output transducer in ABR audiometry. Irrigation fluid, blood or serum can get into the external canal, causing additional/artificial conductive hearing loss and threshold shift intraoperatively and subsequently affecting monitoring accuracy and predicting values. Future research may try to replace insert earphones with loudspeakers to help improve test efficiency as well as better compliance to asepsis protocols intra-operatively.

2. Frequency-specific auditory brainstem responses (fsABRs)

Since broadband stimuli, such as clicks, tend to underestimate hearing loss (especially steep sloping hearing loss), frequency-specific auditory brainstem responses have attracted attention.

Generally, there are two ways to obtain frequency specificity. Some use frequency-specific acoustic signals as stimuli, for instance, tone bursts, filtered clicks, tone pips and chirps, among which tone bursts and tone pips are the most popular; others use masking and filtering techniques. Davis et al. in 1976 recommended to use the "2-1-2" signal cycle tone pip (Davis, 1976), which has been widely used to date.

Later, studies were conducted to explore the accuracy of frequency-specific ABRs. Stapell and Oates suggested that tonal ABRs could be recorded in most circumstances and could predict accurately behavioral thresholds in nearly all populations (Stapells and Oates, 1997). They later conducted a meta-analysis using nearly 30 studies in this field, including infants and adults with or without hearing loss, demonstrating good relationship between tone-pip ABR and behavioral thresholds, with averaged differences of +5.5 to −8.1 dB. Meanwhile, Schoonhoven reported a 15–18 dB difference between click ABR and behavioral thresholds in a hearing