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Ocular and cervical vestibular-evoked myogenic potentials in children with cochlear implant

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HIGHLIGHTS

- Otolithic end organ input pathways are damaged by cochlear implant (CI) surgery, as revealed by oVEMPs (ocular) and cVEMPs (cervical).
- Two patterns of VEMP damage were found in patients after CI: either disappearance of VEMPs waveforms, or impaired VEMPs waveforms with abnormal parameters.
- Both oVEMPs and cVEMPs could be suitable evaluation methods for CI surgery and help doctors improve operation skills.

ABSTRACT

Objective: To define the profile of ocular and cervical vestibular-evoked myogenic potentials (oVEMPs and cVEMPs) in children with cochlear implant (CI), we studied air-conducted sound (ACS)-evoked responses pre- and postoperatively.
Methods: The ACS-evoked oVEMPs and cVEMPs of 31 children with cochlear implantation were investigated. Thresholds, amplitudes, P1 and N1 latencies, and interpeak latencies of VEMPs were measured and analyzed.
Results: Before CI, the response rates of oVEMPs and cVEMPs were 71.0% and 67.7%, respectively. The oVEMPs and cVEMPs on the operated side disappeared after CI, which resulted in a decrease in response rates, whether the device was switched on (12.9% and 32. 0%) or off (19.2% and 34.8%). In the case when VEMPs could be elicited on the operated side after CI, the parameters of waveforms showed abnormal changes, including threshold elevation (maximum of 8.34-dB SPL in oVEMP and 8.75-dB SPL in cVEMP) and amplitude decrease (maximum of 4.10 μV in oVEMP and 191.82 μV in cVEMP).
Conclusions: Disappearance and impairment of VEMPs could be observed after CI, and the waveforms of oVEMP and cVEMP could reflect the degree of damage to the utricle and saccule caused by CI and other related factors.
Significance: The oVEMPs and cVEMPs prove to be accurate methods to evaluate vestibular function in children with CI.

1. Introduction

Cochlear implant (CI) has become a crucial approach for the treatment of deafness, especially in children with bilateral severe sensorineural hearing loss. Sound could be converted to electric signals within the device and transmitted to cochlear nerves via electrodes, which cause the sound to be audible to the patients. However, vestibular dysfunction such as dizziness and imbalance was reported in the studies on CI (Ito, 1998; Brito et al., 2012). The morbidity of postoperative vestibular dysfunction ranges from 0.33% to 75% (Buchman et al., 2004), which implies that the vestibular apparatus could be impaired by the operation. Moreover, children with vestibular dysfunction showed delayed acquisition of head control, independent walking, and gross motor function

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(Inoue et al., 2013). Thus, it is essential to study the influence of CI on the labyrinth, especially on the vestibule.

The cochlea and vestibule share a continuous membranous structure and have similar receptor cells. Therefore, diseases and surgical procedures of the inner ear could probably affect both hearing and the sense of balance. A histopathologic study of human temporal bone reported varied manifestations of injury in vestibular organs (utricle, saccule, and semicircular canals) after CI. Such injuries included collapse, hydrops, fibrosis, and sensory cell reduction of the organ (Tien and Linthicum, 2002; Handzel et al., 2006). The damage rate of the saccule was reported to range from 21% to 100% (Jin et al., 2006; Todt et al., 2008; Licameli et al., 2009; Melvin et al., 2009; Krause et al., 2010). Several pathologic factors could contribute to the damage. Histologic studies on petrous bone demonstrated that the electrode insertion during CI could result in structural damages to the osseous spiral lamina, the basilar membrane, and the vestibular receptors (Tien and Linthicum, 2002). In addition, perilymph loss, acute serous labyrinthitis, endolymphatic hydrops, and electric stimulation were also observed (O'leary et al., 1991; Kubo et al., 2001; Fina et al., 2003). Generally, vestibular otolith organs can be influenced by CI and appropriate measures should be taken to evaluate otolithic function before and after CI.

Two vestibular-evoked myogenic potentials (VEMPs) via air-conducted sound (ACS), the cervical VEMP (cVEMP) and ocular VEMP (oVEMP), were introduced to assess the function of otolith organs in this study. The cVEMP evaluates saccular function (Colebatch and Halmagyi, 1992; Colebatch et al., 1994; Murofushi et al., 1996; Ferber-Viart et al., 1997; Murofushi and Kaga, 2010) and the uncrossed inhibitory vestibulo-collic pathway (Colebatch and Rothwell, 1993; Colebatch et al., 1994; Halmagyi and Colebatch, 1995). The pathway was proved to begin with the saccular macula, via the inferior vestibular nerve, to the vestibular nuclei, the medial vestibulospinal tract, cervical motor neurons, and ended in the sternocleidomastoid muscle. The oVEMP, a fresh member of the VEMP family, could be recorded by the surface electrodes below the eyes when the patients looked up in response to ACS. Although the controversy of end-organ specificity of the oVEMP pathway still persists, recent evidence strongly supported that the utricle was the end organ involved in oVEMP, regardless of the means of stimulation (Curthoys, 2010; Murofushi et al., 2010; Govender et al., 2011). Numerous studies have demonstrated that oVEMP was elicited via a contralateral excitatory potential. The likely pathway begins with the utricular macula, via the superior vestibular nerve, to the vestibular nuclei, the medial longitudinal fasciculus, the contralateral oculomotor nerve nuclei, until the brevissimus oculi (Rosengren et al., 2005; Todd et al., 2007; Iwasaki et al., 2008; Todd et al., 2008; Chihara et al., 2009a; Chihara et al., 2009b; Curthoys et al., 2009; Iwasaki et al., 2009; Smulders et al., 2009; Welgampola et al., 2009; Curthoys et al., 2011; Murofushi et al., 2011; Curthoys et al., 2012; Shin et al., 2012).

If utricular and saccular impairment takes place after CI, the occurrence of abnormalities in ACS-evoked oVEMP and cVEMP responses should be expected. However, no study of a combined test of oVEMP and cVEMP has been reported to estimate the condition of otolith organs after CI. We explored the pattern of VEMP waveforms by the combined test to estimate the potential vestibular damages after CI, thus creating a better understanding of the potential pathogenesis.

2. Materials and methods

2.1. Study population and design

Thirty-one children (mean age 5.52 ± 2.01 years; range 3–12 years, male/female 14/17) were involved in our study. All the patients were diagnosed with bilateral severe sensorineural hearing loss and with no histories of other ear disorders. Intact eardrums and normal middle ear pressures were confirmed by otoscopy and tympanogram, respectively. All the surgeries were the first time for the patients, and all were performed at the ENT department, Second Affiliated Hospital of Xi'an Jiaotong University College of Medicine. Thirty patients were implanted on the right ear and one on the left. The oVEMP and cVEMP were recorded before CI and 1 month after the operation. The VEMPs were recorded when the devices were switched both on and off after CI.

We also recruited 20 healthy children (mean age 6.45 ± 2.19 years; range 4–10 years, male/female 9/11) as controls in this study. Otoscopy, pure-tone audiometry (PTA), and tympanogram were performed in all children. Thirty-two healthy ears were tested for oVEMPs and cVEMPs.

The study was approved by the institutional review board, and each patient and control subject signed the informed consent to participate.

2.2. Cochlear implantations

The surgical procedure consisted of a regular mastoidectomy with posterior tympanotomy, as well as a cochleostomy for electrode implantation. All electrodes were tested and successful implantations were confirmed afterwards.

2.3. Recordings

A sound-proof examination room was employed for testing. ACS with a 500 Hz short tone burst (rise/fall time = 1 ms; plateau time = 2 ms) was used. The electromyographic signal from the stimulated side was amplified by using a GN Otometrics (Taastrup, Denmark) ICS ChartrEP analyzer. The band-pass filter was set at 1–1000 Hz, and the responses to 50 stimuli were averaged twice. ACS was transmitted through a calibrated earphone. A stimulus level of 131-dB SPL was used as the default starting intensity to check whether the subject's VEMPs could be elicited and to identify the waveforms. The stimulus intensity would decrease or increase in steps of 5-dB SPL, depending upon the presence or absence of VEMPs, respectively. The lowest stimulus intensities were acquired when a clear and repeatable biphasic wave was observed, and recorded as the VEMP thresholds.

2.4. oVEMP testing

Each subject was tested in the supine position. The active electrode was placed 1 cm below the lower lid margin of each eye in line with the pupil. The reference electrode was placed 1 cm below the active electrode, and the ground electrode on the midline of the forehead. The interelectrode resistance should be <5 kΩ. Each subject was asked to gaze upwards when hearing sound from the inserted earphone (Iwasaki et al., 2009). Some children could not follow this instruction because they were very young and could hear nothing before CI. Under that circumstance, attention-getting tools such as toys were used.

2.5. cVEMP testing

Each subject was tested in the supine position. The active electrode was placed in the middle of the sternocleidomastoid muscle (SCM), the reference electrode was placed above the sternoclavicular joint, and the ground electrode on the midline of the forehead. The interelectrode resistance should be <5 kΩ. Each subject was instructed to raise her/his head off the pillow to activate the SCM when tone bursts were presented through the inserted earphone