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Auditory brainstem and cortical potentials following bone-anchored hearing aid stimulation

Torsten Rahne*, Thomas Ehelebe, Christine Rasinski, Gerrit Götze

Department of Oto-Rhino-Laryngology, Head and Neck Surgery, University Hospital Halle (Saale), Germany

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ABSTRACT

Patients suffering from conductive or mixed hearing loss and Single-Sided Deafness may benefit from implantable hearing devices relying on bone conducted auditory stimulation. However, with only passively cooperative patients, objective methods are needed to estimate the aided and unaided pure-tone audiogram.

This study focuses on the feasibility aspect of an electrophysiological determination of the hearing thresholds with bone-anchored hearing aid stimulation. Therefore, 10 normal-hearing subjects were provided with a Baha Intenso (Cochlear Ltd.) which was temporarily connected to the Baha Softband (Cochlear Ltd.). Auditory evoked potentials were measured by auditory stimulation paradigm used in clinical routine. The amplitudes, latencies, and thresholds of the resulting auditory brainstem responses (ABR) and the cortically evoked responses (CAEP) were correlated with the respective responses without the use of the Baha Intenso.

The recording of ABR and CAEP by delivering the stimuli to the Baha results in response waveforms which are comparable to those evoked by earphone stimulation and appears appropriate to be measured using the Baha Intenso as stimulator. At the ABR recordings a stimulus artifact at higher stimulation levels and a constant latency shift caused by the Baha Intenso has to be considered. The CAEP recording appeared promising as a frequency specific objective method to approve the fitting of bone-anchored hearing aids.

At all measurements, the ABR and CAEP thresholds seem to be consistent with the normal hearing of the investigated participants. Thus, a recording of auditory evoked potentials using a Baha is in general possible if specific limitations are considered.

1. Introduction

Patients suffering from hearing loss may benefit from hearing aids. Beside the differentiation between external, semi-implantable and fully implantable devices hearing aids the devices can also be distinguished by the transmission pathway of the sound to the cochlea. The most important group comprises the conventional hearing aids which deliver the amplified sound signal into the ear canal. A smaller group is connected to the middle ear bones or the round window membrane and delivers the sound signal by oscillating the respective structures. A further group of hearing aids delivers the sound by bone conduction, either with a conventional external hearing aid or implantable hearing devices. The most prominent one is the bone conduction hearing aid (Baha) comprising an implantable titanium screw placed to achieve osteointegration, a percutaneous coupling, and an electromechanical processor. With this a vibration of the cochlea fluid is evoked by a vibrator (Hakansson et al., 1985; Snik et al., 2005).

The surgical procedure to place the titanium screw is straightforward with low risks. Afterwards, the transducer of the Baha is directly connected to the titanium screw by an abutment (Battista and Ho, 2003). By means of direct bone conduction via an osseointegrated percutaneous titanium implant the Baha achieves an optimal acoustic coupling. Embedding of the otic capsule in the rigid skull base allows transcranial transmission of sound via bone conduction (Tjellstrom et al., 1981).

Currently this bone conduction system has a record of several decades of clinical application and reliability. In contrast to the other partially and totally implantable hearing devices the Baha comprises the advantages of a simple surgical procedure without the risk of inner ear damage, compatibility with magnetic resonance imaging, and the possibility of preoperative testing.

The group of patients who may benefit from a Baha of present standards includes patients with unilateral and/or bilateral

* Corresponding author at: Universitätsklinikum Halle (Saale), Klinik für HNO-Heilkunde, Magdeburger Str. 12, 06112 Halle (Saale), Germany. Tel.: +49 345 557 5362; fax: +49 345 557 1859.
E-mail address: torsten.rahne@medizin.uni-halle.de (T. Rahne).

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conductive or mixed hearing loss, with a sensorineural hearing loss of at most 50–60 dB HL and speech discrimination scores of 60% or greater (Bosman et al., 2009; Snik et al., 2004, 2005).

Also, profound unilateral sensorineural hearing loss with normal hearing on the other side can be treated with a Baha. Here, the Baha acts as a bone conduction CROS (contralateral routing of off-side signal) device and transmits the sound signal from the deaf side through the skull to the contralateral cochlea. In general, the satisfaction rate is very high for patients using the Baha system (Battista and Ho, 2003; Priwin et al., 2007; Tjellström and Hakansson, 1995).

For testing the performance and the individual outcome of the Baha device, a temporary transcutaneous coupling of the device is provided by the Baha test device and the Baha Softband (Cochlear Ltd.). With this, the Baha sound processor is connected to a special adapter and pressed onto the patients' skin. Especially for children, the Baha Softband appears to be an effective method of hearing rehabilitation. The resulting hearing threshold and the speech development with the Baha Softband are almost equal to that achieved with a conventional bone conductor (Hol et al., 2005; Verhagen et al., 2008). As the Baha Softband is a reversible and non-invasive method of providing bone conduction hearing, it appears as an appropriate method to simulate measures with normal hearing control groups and hearing-impaired listeners.

In several cases, especially with only passively cooperative subjects and young children, objective methods are needed to estimate the aided and unaided pure-tone audiogram. In these cases, the auditory evoked potentials are widely used. Stimulated with sound, the EEG undergoes typical changes with are time-correlated with the sound stimuli (Eggermont, 2007). Dependent on their generating origin on the neuronal pathway the auditory evoked potentials (AEP) reveal typical latencies and amplitudes in the resulting waveforms. The auditory brainstem responses (ABR) appear as a series of vertex-positive waves that occur within 15 ms of the onset of a transient stimulus. These responses are widely used in clinical routine to measure hearing thresholds (Burkard and Don, 2007).

Generated by neuronal structures in or near the auditory cortex the cortically auditory evoked potentials (CAEP) are of clinical interest as frequency specific thresholds are measurable (Martin et al., 2007). They can be elicited by clicks, tone bursts and speech sounds. Their amplitude and latency undergo significant maturation until the age of 6 years. This and the fact that the listeners must be in an awake and alert state limit the application in clinical routine. Here we focus on adults so that the advantage of a frequency-specific determination of thresholds prevails. Therefore the P1–N1–P2 complex as a waveform with a latency of 50–175 ms is used to estimate the individual pure-tone audiogram (Cone-Wesson and Wunderlich, 2003; Hyde, 1997).

Despite the fact that the auditory signal is incalculable modified by the signal processor, the measurement of AEP is also supposed to be integral to the treatment of patients with hearing aids and cochlear implants. In particular, these techniques are useful in the management of children (Kileny, 2007). Even though no AEP measures using conventional hearing aid stimulation are described so far, several studies report successful measures of auditory evoked potentials with cochlear implant users. Hereby, the latency of the responses may be shifted by the implant processing. Prolonged wave V latency for the basal electrodes (Firszt et al., 2002) as well as shorter latencies of the waves III and V using a single channel electrode (Miyamoto, 1986) were observed. In general, the amplitude of the resulting waveforms II, III, and V were correlated with the stimulating place within the cochlea represented by the respective electrode number (Firszt et al., 2002; Kubo et al., 2001). However, the electrically evoked CAEP used with cochlear implant users are more prevalent. Hereby the determination of a threshold is in general possible and reliable (Beynon et al., 2002; Eggermont et al., 1997; Jordan et al., 1997; Kileny, 2007).

Measuring AEP with Baha users is closely related to measuring AEP by conventional bone conduction stimulation. When measuring ABR, it has to be considered that the latencies for bone conduction are longer compared to that for air conduction. This effect is evident for both clicks and tone bursts and not due to differences between the frequency responses of air and bone conduction transducers (Gorga et al., 1993; Mauldin and Jerger, 1979; Tringali et al., 2008). Rather, there is a delay in the transfer of vibratory energy from the skull bone to the cranial cavity (Sohmer and Freeman, 2001). For CAEPS, the latencies do not differ between air and bone conduction (Tringali et al., 2008).

A clinical AEP measurement using a Baha was reported for patients with unilateral sensorineural hearing loss (Tringali et al., 2008). They used a free field sound stimulation with a sound intensity level of 80 dB HL which required masking or obstruction of the healthy ear. Using a Baha Cordelle (Cochlear Ltd., Australia) clear ABR and CAEP waveforms were elicited which were comparable to the stimulation by headphone. However, no threshold measurement was performed for the ABR or the CAEP recordings. Further, a better signal-to-noise ratio of the presented stimuli would be achieved if the sound stimuli would be delivered electrically to the external audio port of the BAHA.

A further issue is the electrical artifact generated by the implanted device. As with cochlear implants the artifact can be kept under control (Martin, 2007), it interferes with neural responses with BAHA users. Following Tringali et al. (2008), it is more significant with louder stimulation levels and also with ABR compared to the CAEP measures.

Extending the results of Tringali et al. (2008), this study focuses on the feasibility aspect of the determination of hearing thresholds with Baha stimulation. Therefore, normal-hearing subjects were provided with a Baha Intenso device (Cochlear Ltd.) connected to a Baha Softband. Measuring the AEP for (1) click stimuli with an ABR paradigm, and (2) pure tone stimuli with a CAEP paradigm, the amplitudes, latencies and thresholds were correlated with the respective responses without the use of the Baha.

2. Material and methods

2.1. Subjects

Ten normal hearing adults between the ages of 22 and 37 years ($M = 25$ year, four females, 6 males) participated in the study. All participants passed a hearing screening (thresholds of 10 dB HL or better at frequencies of 0.5, 1, 2, and 4 kHz) and had no reported history of hearing or neurological problems. Participants gave informed consent after the procedures were explained to them, in accordance with the ethical guidelines of the Martin-Luther-University of Halle-Wittenberg, where the study was conducted. The procedures conform to the Code of Ethics of the World Medical Association (Declaration of Helsinki).

2.2. Experimental setup and procedure

The experiment consisted of four stimulation conditions varying between bone conduction (Baha) and air conduction (headphone) in the ABR and CAEP portions. All conditions were presented in pseudorandomized order. The total duration of the experiment includes breaks and was 3.5 h.

For all conditions, the subjects were comfortably seated in a sound attenuated booth. All stimuli were generated by the ESTIM2 (ESMED) signal generator and amplifier which also recorded the EEG. Ag/AgCl electrodes were connected for the ipsilateral channel to the electrodes sites F3 and the left mastoid and at F4 and the right mastoid for the contralateral channel. Prior averaging the