Superiority of tympanic ball electrodes over mastoid needle electrodes for intraoperative monitoring of hearing function

Clinical article

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Object. Recording the auditory brainstem response (ABR) is a common method for monitoring the integrity of auditory pathways during surgery in the cerebellopontine angle. Electrocochleography (ECochG) is an alternative means of intraoperative neuromonitoring. In the present study the authors compared the practicability and prognostic significance of these two methods by performing simultaneous recordings in the operating room.

Methods. Between 2006 and 2011, 125 patients (mean age 55 years) underwent surgery in the cerebellopontine angle. Seventy-one percent of the patients presented with a hearing deficit, and 37% had useful hearing but with slight functional impairment. Auditory brainstem response was recorded with a subdermal needle electrode at the mastoid. For ECochG recording, a noninvasive ball electrode was attached to the tympanic membrane. Amplitudes obtained from both ECochG and ABR audiometry were compared and correlated to pre- and postoperative hearing deficits.

Results. Simultaneous intraoperative monitoring via ABR and ECochG was possible in 114 cases (91%). Postoperatively, 42% of patients showed some degree of new hearing deficit, whereas 4% had improvement. The mean amplitudes in ECochG monitoring were significantly higher (0.18 ± 0.006 μV; p < 0.05) than the ABR potentials (0.08 ± 0.006 μV; p < 0.05). All waves recorded at the mastoid needle electrode could be recognized in the potentials of the tympanic ball electrode. Hearing outcome correlated more reliably with the relative amplitude changes in Waves III and V in ECochG (III: p = 0.0008, V: p = 0.0015) than in ABR monitoring (III: p = 0.2075, V: p = 0.0398).

Conclusions. Intraoperative monitoring of the auditory system by recording with noninvasive tympanic ball electrodes is more practicable than with subcutaneous needle electrodes at the tragus. Since there is also a reliable correlation between ECochG and clinical outcome, the method can replace common ABR recording during surgery in the cerebellopontine angle.

(http://thejns.org/doi/abs/10.3171/2014.1.JNS13396)

KEY WORDS • intraoperative neuromonitoring • hearing function • BERA • evoked potentials • cerebellopontine angle • functional neurosurgery

Depending on the type of lesion, surgery within the cerebellopontine angle harbors a variable risk of postoperative hearing impairment.2,6,14,26 Therefore, in most centers intraoperative neuromonitoring (IOM) is performed using auditory brainstem response (ABR) audiometry. Intraoperative ABR monitoring is a useful aid in hearing preservation by warning the surgeon of operative events that threaten the integrity of the cochlear nerve.10,19,23,26 Moreover, it can significantly improve the rate of surgery-related hearing impairment, especially in small tumors.7 However, ABR has shortcomings for IOM. First, there is a great distance between the brainstem as generator of potentials and the electrodes, which results in small signal amplitudes and a high impact of electrical artifacts on waveforms.27 Second, averaging 1000–2000 stimuli is necessary to arrive at a reasonable signal-to-noise ratio, leading to long periods between damage and detection, and renders real-time monitoring impossible.4

For IOM of the function of the cochlea and cochlear nerve, electrocochleography (ECochG) via trans tympanic electrodes resting on the promontory provides an alternative.17,28 Given the proximity of the electrode to generators in the cochlea and cochlear nerve, the compound action potential (CAP) has a greater amplitude than the surface ABRs.5 Potentials with a higher latency generated by the brainstem have not been routinely evaluated with these electrodes. The disadvantage of trans tympanic electrodes is that they are invasive, and their placement usually requires a myringotomy performed by an ear, nose, and throat specialist, which also prolongs the preoperative preparation.8 Therefore, these electrodes are mainly applied in ear and cochlear surgery.5,15 However, potentials can also be detected by noninvasive electrodes inserted through the external auditory canal and placed directly lateral to the tympanic membrane.10,18,25 Although ECochG is commonly used in Ménière’s disease and monitoring for inner ear surgery, the closer proximity of the electrode to the brainstem could improve the detection of potentials generated by brainstem structures as well.4,15

Thus, the aim of this study was to evaluate the dif-
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differences in simultaneous recordings from mastoid needle electrodes and tympanic ball electrodes for monitoring during surgery within the cerebellopontine angle.

Methods

This study was performed in accordance with the ethical standards of the local ethics committee and the Declaration of Helsinki.

Patient and Lesion Characteristics

Between 2006 and 2011, we performed 125 consecutive surgeries for lesions located in the cerebellopontine angle. In all cases, IOM was attempted using ABR audiometry and ECochG. The mean age of the patients was 55 years (range 21–83 years). Sixty percent of the patients were female and 40% were male. Indications for surgery were vestibular schwannoma in 46 patients (37%), meningioma in 35 (28%), trigeminal neuralgia in 10 (8%), other schwannomas in 9 (7%), hemifacial spasm in 5 (4%), and a wide variety of other conditions in 20 (16%), including jugular glomus tumor, arteriovenous malformation, cholesteatoma, chondrosarcoma, ependymoma, metastases, and cavernoma in 20 (16%). Sixty-one lesions were right-sided (49%) and 64 were on the left (51%). Out of 125 patients, 71% presented with a hearing deficit, while 29% had no deficit. Thirty-seven percent of the patients still had useful hearing but with slight functional impairment (Fig. 1).

Clinical Assessment

Every patient was thoroughly examined by a trained otorhinolaryngologist and underwent audiographic assessment prior to surgery, within the 1st postoperative week, and during follow-up. Hearing was classified into 4 groups: normal hearing, impaired but still useful hearing, non-useful hearing, and deafness. Useful hearing was defined as the ability to use a telephone on the affected side. Thirty-seven percent of patients suffered from non-useful hearing preoperatively (Fig. 1).

Tumor diameter was measured at the widest extension of the tumor on axial contrast-enhanced T1-weighted MRI slices.

Surgical Procedure

Two experienced skull base surgeons (B.M. and J.L.) performed a retrosigmoid craniectomy in all cases.

As volatile anesthetics severely interfere with IOM, we used total intravenous anesthesia with continuous infusion of propofol and remifentanil. Throughout the operation, body temperature was maintained at physiological levels via the routine use of an air warmer system (WarmTouch, Covidien-Nellcor) to avoid hypothermia as a confounder. Patient position was supine with a pillow under the ipsilateral shoulder with an overall 90° head rotation to the contralateral side.

The ECochG electrode used in this study was developed by one of the authors (S.K.R.) in cooperation with Inomed Medizintechnik. A ball was mounted on a spring, which was guided through the earplug of the sound generator. For our purposes, the spring of the ECochG electrode was shortened to 2 cm after an initial tympanic membrane laceration occurred in one patient. Before surgery and after patient fixation in the head clamp, the intrameatal ECochG electrode was placed (Fig. 2). For ABR recording we used 27-gauge disposable subdermal needle electrodes (AD-Tech Medical Instrument Corp. and Inomed Medizintechnik) at the vertex and ipsilateral mastoid (active: Cz, reference: mastoid [A1 and A2]).

The click stimuli were applied at 11.7 Hz as alternating polarity clicks with a stimulus duration of 100 μsec and a 90-dB sound pressure level by the ear-insert stimulating unit. The ear was sealed with waterproof dressing, and the contralateral ear was masked with white noise at 60 dB. Both ABR and ECochG recording began with the incision and continued until 30 minutes after dural closure. Baseline responses were recorded immediately after durotomy and CSF drainage.

Processing of the acquired data was achieved using the EpocheXP neuromonitoring system (Axon Systems Inc.) or the ISIS IOM system (Inomed Medizintechnik). We used bandpass filters between 100 and 3000 Hz for ABR as well as ECochG detection. Averaging was performed using 1000 stimuli for each method. An example of the recorded potentials of both modalities is provided in Fig. 3. For IOM of the acoustic nerve, latency and amplitude of Waves I, III, and V were monitored for any change. The surgeon was immediately informed of any consistent change from baseline values for amplitude or latency. However, a 50% reduction in amplitude or a 1-msec increase in the latency of Wave I, III, or V was considered significant.

For this study, another investigator who had not participated in IOM evaluated the recorded IOM data and was blinded to hearing outcome as well as the results of the other method.

Statistical Analysis

For testing the distribution of several attributes, a chi-square or Fisher exact test was performed. Differences between two groups were tested using the Mann-Whitney-Wilcoxon test for multiple comparisons on ranks for independent samples. Differences between groups were tested using the Kruskal-Wallis test for nonparametric 1-way ANOVA, followed by Dunn’s test as the post hoc
test. All results are presented as the means ± standard deviation. Variances were given as the median and range (Prism 5.0c, GraphPad Software), and the significance level was set at p < 0.05.

Results

Monitoring of ABR and ECochG amplitudes was successful in 114 cases (91.2%). In the remaining 11 cases, hearing had been severely impaired before surgery. The mean follow-up was 37.5 ± 13.3 months (range 14.4–59.3 months).

Hearing Outcome

Postoperatively, 42% of patients showed some degree of new hearing deficit, whereas 4% had improvement. Thus, preoperative hearing was preserved or improved in 58% of patients. Overall, 66% of patients showed non-useful hearing on long-term follow-up.

In patients harboring tumors, hearing preservation did not correlate to tumor size. In those with normal hearing preoperatively, tumor diameter was 2.4 cm, while it was 2.3 cm in patients with reduced but useful hearing preoperatively and 2.9 cm in patients with non-useful hearing preoperatively. In preoperatively deaf patients (10 patients), tumor diameter was 2.5 cm. Patients with improved hearing after surgery had a 3.0-cm tumor diameter, while it was 2.5 cm in those whose hearing was unchanged and 2.4 cm in those with any degree of new hearing deficit.

Electrocochleography Versus ABR Amplitudes

The waves recorded at the tympanic ball ECochG electrode had significantly greater amplitudes than those obtained with the ABR mastoid needle electrodes. The mean ECochG amplitude for Waves I, III, and V (overall: 0.18 ± 0.04 μV) was 2.25 times greater than that recorded by the mastoid needle electrodes (overall: 0.08 ± 0.006 μV, p < 0.05; Figs. 3 and 4). In recordings at the end of surgery, the differences in the amplitudes of ECochG and ABR had not changed. Latencies for ECochG and ABR were similar and did not show any significant difference (Table 1).

Correlation of Amplitude Changes to Hearing Function

When analyzing the relative changes from pre- to postoperative amplitudes and latencies, hearing outcome correlated more reliably with the relative perioperative amplitude changes of Waves III and V in ECochG (III: p = 0.0008, V: p = 0.0015) than in ABR monitoring (III: p
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= 0.2075, V: p = 0.0398; Fig. 5). Again, latencies did not show any significant difference (Table 2).

Complications and Limitations

The only complication encountered was a rupture of the tympanic membrane in one patient. This rupture closed spontaneously, and no further sequelae were observed on long-term follow-up. In response to this complication, we shortened the spring of the ECochG electrode to 2 cm. Thereafter no further complication was noted.

No limitation of the tympanic ball electrode was seen, and there was no case in which ABR monitoring was possible but ECochG failed to provide IOM data.

Discussion

Outcome

It has been shown that IOM of auditory brainstem potentials can improve outcomes in hearing function. Consequently, IOM must be as optimal as possible to achieve high sensitivity and specificity. As in most other reports, changes in IOM correlated well with postoperative hearing in the present study. Overall, preoperative hearing was preserved or improved in 58% of our patients, which is highly comparable to the rate in other series.

Electrode Placement

The ECochG electrode does not entail any additional work or setup than the ABR electrode does. On the contrary, it is easy to place, and after shortening it to 2 cm, no complications occurred due to the use of the noninvasive ECochG electrode. Moreover, compared with other near-field techniques, ECochG is noninvasive and does not interfere with the operative field as other techniques do.

Qualitative Differences

Our data showed that all early auditory evoked potentials, including Waves III and V, are detectable with this newly designed, noninvasive, extratympanic intrameatal ECochG ball electrode (Fig. 3). We also noted that especially in patients with impaired hearing, identifying Waves I, III, and V of the ABR is difficult but significantly easier with parallel ECochG recording. We also observed that the extratympanic intrameatal electrode provides reliable and reproducible responses, which were highly comparable with the simultaneously recorded ABR potentials.

Moreover, because of the consistent waveform quality and its ease of placement, the extratympanic intrameatal electrode should be favored over the transtympanic

<table>
<thead>
<tr>
<th>Wave &amp; Modality</th>
<th>Preop</th>
<th>Postop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude (µV)</td>
<td>Latency (msec)</td>
</tr>
<tr>
<td>Wave I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABR</td>
<td>0.09 ± 0.025</td>
<td>1.6 ± 0.17</td>
</tr>
<tr>
<td>ECochG</td>
<td>0.17 ± 0.039</td>
<td>1.7 ± 0.37</td>
</tr>
<tr>
<td>Wave III</td>
<td></td>
<td></td>
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<tr>
<td>ABR</td>
<td>0.1 ± 0.031</td>
<td>3.7 ± 0.24</td>
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<tr>
<td>ECochG</td>
<td>0.13 ± 0.053</td>
<td>3.7 ± 0.21</td>
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<tr>
<td>Wave V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABR</td>
<td>0.11 ± 0.035</td>
<td>5.8 ± 0.31</td>
</tr>
<tr>
<td>ECochG</td>
<td>0.13 ± 0.05</td>
<td>5.9 ± 0.24</td>
</tr>
</tbody>
</table>

* Latencies did not show any significant differences between the two modalities.
ECochG needle electrode.22 Despite the lower amplitude of the intrameatal electrode, the CAP of the cochlear nerve is still sufficiently well defined for IOM and still superior to the traditionally used ABR, and ECochG is a relatively simple and robust procedure.15 In another study, no significant difference in the CAP was found between transtympanic and extratympanic electrodes in healthy volunteers.21

Quantitative Diversity

The CAP of the ECochG is significantly greater in amplitude than Wave I of the ABR and was easily monitored. Depending on the degree of hearing impairment before treatment, ABR waveforms may be poorly defined because of very low signal amplitudes, so that monitoring is often difficult in patients with already impaired hearing.3,5,7,15 All waves recorded at the ECochG ball electrode showed significantly higher amplitudes than the potentials from the traditional mastoid electrode placement in our study (Figs. 3 and 4).

Recording with near-field electrodes placed near the other end of the cochlear nerve has proved more difficult, because the nerve has to be exposed first and because electrodes placed directly on the nerve may significantly interfere with the operative field.11–13,24

Predictive Value

The most important finding of this study was that recordings from the tympanic membrane with a ball electrode resulted in an improved predictive value for postoperative hearing impairment (Fig. 5). Other authors have reported Wave III as the most sensitive marker for surgery-related impairment in hearing function.9,10 Several studies were able to reveal that the most harmful surgical manipulations with regard to acoustic nerve function were drilling, pulling at the nerve, and direct nerve manipulation.7,10,15 Thus, recognizing significant waveform changes is crucial to allow modification in microsurgical strategy. Thus, the significantly higher voltage and signal-to-noise ratio of the near-field recordings obtained using the tympanic ball electrode, as compared with those obtained with the mastoid needle electrode, are clear advantages.

Conclusions

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### TABLE 2: Relative changes from pre- to postoperative amplitudes and latencies of Waves III and V, relative to the changes in hearing function

<table>
<thead>
<tr>
<th>Hearing &amp; Modality</th>
<th>Wave I</th>
<th>Wave III</th>
<th>Wave V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude Change (%)</td>
<td>Latency Change (%)</td>
<td>Amplitude Change (%)</td>
</tr>
<tr>
<td>improved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABR</td>
<td>118.3 ± 2.3</td>
<td>100.0 ± 14.0</td>
<td>133.3 ± 47.1</td>
</tr>
<tr>
<td>ECochG</td>
<td>103.9 ± 45.9</td>
<td>94.4 ± 7.9</td>
<td>119.8 ± 12.3</td>
</tr>
<tr>
<td>unchanged</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABR</td>
<td>98.2 ± 36.0</td>
<td>104.2 ± 13.1</td>
<td>91.0 ± 23.1</td>
</tr>
<tr>
<td>ECochG</td>
<td>97.0 ± 46.2</td>
<td>107.0 ± 14.5</td>
<td>92.7 ± 17.6</td>
</tr>
<tr>
<td>worse</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABR</td>
<td>87.7 ± 43.1</td>
<td>103.7 ± 15.4</td>
<td>87.1 ± 24.0</td>
</tr>
<tr>
<td>ECochG</td>
<td>104.9 ± 75.8</td>
<td>106.1 ± 11.1</td>
<td>76.8 ± 20.6</td>
</tr>
</tbody>
</table>
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ECochG electrode is superior to conventional mastoid needle ABR monitoring with regard to wave amplitudes, signal-to-noise ratio, and prognostic value for postoperative hearing function. Not only Wave I, but also the waves generated by the brainstem (Waves III and V) can be monitored. Thus, we consider the use of a tympanic ball electrode during surgery within the cerebellopontine angle as the method of choice in monitoring auditory pathways in the future.

Disclosure

The study was completely financed by institutional grants from the Department of Neurosurgery. The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Lehmberg, Krieg. Acquisition of data: Kempf, Droese. Analysis and interpretation of data: Lehmberg, Krieg, Kempf. Drafting the article: Krieg. Critically revising the article: all authors. Approved the final version of the manuscript on behalf of all authors: Lehmberg. Statistical analysis: Krieg. Administrative/technical/material support: Lehmberg, Krieg, Droese, Rosahl, Meyer. Study supervision: Lehmberg.

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For this issue: please include this information when citing this paper: published online February 21, 2014; DOI: 10.3171/2014.1.JNS13396.

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