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What is This?
Intraoperative Monitoring of Hearing Improvement during Ossiculoplasty by Laser-Doppler Vibrometry, Auditory Brainstem Responses, and Electrocochleography

Krzysztof Morawski, MD, PhD1, Kazimierz Niemczyk, MD, PhD1, Jacek Sokolowski, MD, PhD1, Aleksandra Hryciuk, MD1, and Robert Bartoszewicz, MD, PhD1

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Keywords
ossiculoplasty, electrocochleography, laser-Doppler vibrometry, intraoperative monitoring of hearing

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Despite the recent progress observed in middle ear surgery effects, one of the remaining challenges is a long-term hearing improvement (HI). One of the factors influencing postoperative short- and long-term HI is optimal intraoperative ossicular prosthesis placement to achieve the maximal air-bone gap closure (ABG-closure). Although the surgeon’s experience is substantial in the HI process, objective techniques for intraoperative monitoring (IM) of the ossiculoplasty efficiency may improve postoperative hearing results. Only a few studies have described the idea of electrophysiological IM of hearing during ossiculoplasty, mostly reporting on auditory brainstem responses (ABRs) and sporadically electrocochleography (ECochG).1-3 There are many studies on laser-Doppler vibrometry (LDV) being used to evaluate sound-transmitting properties of tympanic membrane grafts, hearing ossicles, and prostheses. However, nearly all the experiments were performed on cadaver temporal bones. Only a few reports have described the intraoperative clinical application of LDV,4,5 yet none has exemplified the combined application of both electrophysiological and LDV techniques. In this article, we describe the combined strategy (ABR-ECochG-LDV) designed to conduct IM of hearing improvement during middle ear ossicular reconstructive surgery.

Methods and Patients
Eleven patients with chronic otitis and cholesteatoma, ranging in age from 18 to 36 years, underwent 2-stage canal wall-up tympanoplasty. In all cases, the incus was damaged while the malleus and stapes superstructure were preserved. Prosthesis was prepared using autologous incus or temporal bone. Pure-tone audiometry (PTA) was performed before the first- and second-stage surgery and 6 months after the second-stage ossiculoplasty. During the first-stage surgery, a typical attico-antro-mastoidectomy with posterior tympanotomy was performed with cholesteatoma removal and tympanic membrane reparation by temporal fascia. In all patients included in this study, after the first-stage surgery, a dry ear with a healed graft was observed.

Table 1. Minimal, Maximal, and Mean Values of Preoperative and Postoperative PTA4 Thresholds Calculated as an Average at 4 Frequencies ([500 Hz + 1000 Hz + 2000 Hz + 4000 Hz]/4).<sup>a</sup>

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD</th>
<th>Min-Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative PTA4 threshold, dB</td>
<td>52.1 ± 13.8</td>
<td>35.00-73.75</td>
</tr>
<tr>
<td>Postoperative PTA4 threshold, dB</td>
<td>35.7 ± 13.8</td>
<td>18.75-63.75</td>
</tr>
<tr>
<td>Postoperative LDV4 threshold, dB</td>
<td>21.6 ± 4.5</td>
<td>15.00-30.00</td>
</tr>
<tr>
<td>ABG4-closure, dB</td>
<td>16.9 ± 7.0</td>
<td>10.00-28.75</td>
</tr>
<tr>
<td>ABR4-closure, dB</td>
<td>13.7 ± 9.8</td>
<td>3.75-38.75</td>
</tr>
<tr>
<td>RW-ECochG4-closure, dB</td>
<td>24.9 ± 9.4</td>
<td>11.75-43.00</td>
</tr>
</tbody>
</table>

Abbreviations: ABG, air-bone gap; ABR, auditory brainstem response; dB, decibel; ECochG, electrocochleography; HL, hearing level; LDV, laser-Doppler vibrometry; PTA, pure-tone audiometry; RW, round window.

<sup>a</sup>ABG4-closure, ABR4-closure, and RW-ECochG4-closure are expressed as a difference between preoperative and postoperative thresholds.

1Department of Otolaryngology, Medical University of Warsaw, Warsaw, Poland

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Corresponding Author:
Krzysztof Morawski, MD, PhD, Department of Otolaryngology, Medical University of Warsaw, Banacha 1a St, 02-097 Warsaw, Poland. Email: morawski@neurotology.pl
The Smart-EP equipment (Intelligent Hearing Systems, Inc, Miami, Florida) was used for electrophysiological recordings during the second-look surgery. Needle electrodes were fixed in the head apex (reference) and at the hairs-forehead border (ground). A needle electrode for round window (RW)–ECochG was placed into the round window niche, while for ABR, it was positioned on the mastoid tip. Ossicular prosthesis movability was evaluated using LDV (OFV-534 Vibrometer with OFV-5000 Vibrometer Controller, manufactured by Polytec GmbH, Waldbronn, Germany). Through posterior tympanotomy, a small piece of the laser-Doppler mirror was placed on the prosthesis to record the reflecting laser beam, allowing evaluation of ossicular chain vibration.

Intraoperative efficiency of the ossiculoplasty was measured using one acoustic stimulation (tone bursts: 0.5, 1.0, 2.0, and 4.0 kHz). Evaluated LDV thresholds in this ear ranged between 30 and 40 dB normal hearing level (nHL).

**Figure 1.** Laser-Doppler vibrometry (LDV) recorded intraoperatively via posterior tympanotomy in a patient after ossiculoplasty. The middle ear sound transmitting system was stimulated acoustically by tone bursts (0.5, 1.0, 2.0, and 4.0 kHz). Evaluated LDV thresholds in this ear ranged between 30 and 40 dB normal hearing level (nHL).
2.0, and 4.0 kHz) for both electrophysiological tests and LDV.

For combined LDV-ABR-RW-ECochG measurements, a prototype IM device was composed of Smart-EP and OVF-534 systems. The analog output of the Vibrometer Controller was connected to the analog input port of the Smart-EP system, which provided the auditory stimulation and averaged the recorded ABR, RW-ECochG, and laser-Doppler signals.

Approval was obtained from the Medical University of Warsaw Bioethical Board.

Results

Intraoperative monitoring prolonged the surgical procedure for about 15 to 20 minutes. In Table 1, audiological and intraoperative electrophysiological data are presented. Electrophysiological HI, calculated intraoperatively, ranged from 3.75 to 43 dB, and on average at 4 frequencies ([0.5 Hz + 1.0 Hz + 2.0 Hz + 4.0 Hz]/4) was better for RW-ECochG by 11.2 dB. Intraoperatively calculated ABR4-closure was lower by 3.2 dB compared with ABG-closure, calculated 6 months following ossiculoplasty, while RW-ECochG4-closure was higher by around 8 dB. Postoperative LDV4 thresholds, compared with postoperative PTA4 thresholds, were better by 14.1 dB. Figure 1 and Figure 2 show an example of intraoperatively recorded LDV characterized by easy identification of LDV thresholds at all frequencies and RW-ECochG recorded at the same frequency set. Correlations between ABG-closure and RW-ECochG4-closure as well as between LDV4 threshold and postoperative PTA4 thresholds were statistically significant but not for ABR4-closure (Figure 3).

Correlations between ABG closure and each modality used intraoperatively were undertaken after the success of the ossiculoplasty was known to determine which method of IM best correlated with the hearing result.

Discussion

Electrophysiological techniques are to be used for intraoperative hearing threshold assessment. In cases of mixed hearing loss, where electrophysiological responses are difficult for interpretation, the LDV technique is particularly applicable.

The time of the IM procedure should be no longer than 20 minutes. Easy interpretation of collected data, high reproducibility of recordings, and high sensitivity of method...
revealing detection of even 5- to 10-dB changes are also expected.1-3

Electrophysiological techniques supported with simultaneous LDV recording seem to fulfill these criteria. In patients with a narrow oval window niche, overhanging facial nerve, and tympanosclerosis in which precise ossicular placement is particularly difficult, application of combined modalities may also support the choice of proper surgical procedures.

Maximal HI would be much easier achieved if the surgeon would be intraoperatively informed about efficiency of sound transmission through the ossicular prosthesis. Intraoperative monitoring of the reconstructed ossicular chain movement and functional status of the ossiculoplasty verify hearing results. The above may permit the immediate repositioning of the prosthesis. Recently, only a few studies have provided information on LDV as a tool to assess prosthesis movability during live surgery, with no studies on simultaneous intraoperative recordings of electrophysiological technique and LDV.4,5

**Conclusion**

To our knowledge, this project is the first that studies simultaneous application of auditory evoked responses (ABR and RW-ECochG) and LDV. Unlike RW-ECochG, ABR did not show any statistically significant correlation to hearing results, so it may not be helpful in determining prosthesis placement. The studied strategy may possibly reduce time needed for IM of hearing and provide new insight into the middle ear mechanics. The above results suggest that optimization of ossicular placement at the time of surgery with IM might lead to better postoperative hearing results, although this would need to be assessed in future clinical trials.

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**Author Contributions**

Krzysztof Morawski, substantial contributions to conception and design, surgeon, analysis and interpretation of data, drafting the article, final approval of the version to be published; Kazimierz Niemczyk, substantial contributions to conception and design, surgeon, acquisition of data, revising the article critically, final approval of the version to be published; Jacek Sokolowski, acquisition and analysis of data, revising the article critically, final approval of the version to be published; Aleksandra Hryciuk, acquisition and analysis of data, drafting the article, final approval of the version to be published; Robert Bartoszewicz, acquisition and analysis of data, drafting the article, final approval of the version to be published.

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