INDEX COPERNICUS INTERNATIONAL

CASE REPORT

Intraoperative hearing evaluation during tympanoplasty – surgical technique and measurement method using OssiMon LAIOM system

Pomiary śródoperacyjne słuchu podczas operacji tympanoplastycznych – metoda chirurgiczna i technika pomiaru za pomocą systemu OssiMon LAIOM

Kazimierz Niemczyk[1], Krzysztof Morawski[1], Rafael Delgado[2], Maria Małkowska[1], Robert Bartoszewicz[1], Jacek Sokołowski[1], Magdalena Lachowska[1]

[1]Department of Otolaryngology, Medical University of Warsaw
[2]Intelligent Hearing System, Miami, USA

Article history: Received: 20.08.2018 Accepted: 15.09.2018 Published: 30.09.2018

ABSTRACT: We present a surgical technique of closed tympanoplasty for chronic otitis, together with an intraoperative functional evaluation system with the OssiMon LAIOM software. The technique can be used in one or two steps for an intraoperative evaluation of the functional effect during ear operation. Using OssiMon LAIOM, we were able to simultaneously measure the auditory steady state response (ASSR), as well as to perform laser dopler vibrometry (LDV). For electrophysiologic measurements, OssiMon LAIOM uses the Intelligent Hearing System platform, and the Polytec single-point laser to evaluate the ossicular mobility. The measurements can be conducted using both methods at the same time or separately, applying each method independently. The OssiMon LAIOM software records the ASSR response intraoperatively and marks it automatically on the audiogram with the preoperative hearing level. The ossicular vibration level is determined based on the measured LDV response. To the best of our knowledge, OssiMon LAIOM is the first solution allowing to objectively measure the effectiveness of tympanoplasty using two methods simultaneously, i.e. ASSR and LDV. The system could be widely applied in functional evaluation of the middle ear and in clinical practice.

KEYWORDS: otology, eardrum, external auditory canal, stapes, hearing tube, auditory ossicles, tympanic cavity

STRESZCZENIE: Autorzy przedstawiają technikę operacji tympanoplastycznych typu zamkniętego stosowaną w leczeniu przewlekłych zapaleń uszu oraz system śródoperacyjnej oceny wyniku czynnościowego z aplikacją OssiMon LAIOM. Opracowana technika operacyjna może być stosowana jednoetapowo lub dwuetapowo umożliwiając wykonywanie śródoperacyjnych pomiarów efektu czynnościowego operacji ucha. Za pomocą aplikacji OssiMon LAIOM mogą być zastosowane jednocześnie pomiary elektrofizjologiczne potencjałów stanu ustalonego (ASSR – auditory steady state response) oraz pomiary drgań kosteczek słuchowych (LDV – laser dopler vibrometry). OssiMon LAIOM wykorzystuje do pomiarów elektrofizjologicznych ASSR platformę Intelligent Hearing System, a do oceny ruchomości kosteczek słuchowych jednopunktowy laser Polytec. Pomiary można wykonywać jednocześnie obiema metodami lub pojedynczo każdą z nich niezależnie od siebie. Aplikacja OssiMon LAIOM pozwala na uzyskanie podczas operacji zapisu odpowiedzi ASSR w formie automatycznie zaznaczonej odpowiedzi na siatce audiogramu z zapisanym poziomem słuchu przed operacją. Próg drgań kosteczek słuchowych jest ustalany na podstawie rejestracji odpowiedzi LDV. OssiMon LAIOM wg wiedzy autorów jest pierwszym rozwiązaniem umożliwiającym obiektywne pomiary efektywności tympanoplastyk za pomocą jednocześnie stosowanych 2 metod ASSR i LDV. System ten może mieć bardzo duże zastosowanie w badaniach funkcji ucha środkowego oraz w praktyce klinicznej.

SŁOWA KLUCZOWE: otologia, błona bębenkowa, przewód słuchowy zewnętrzny, strzemiączko, trąbka słuchowa, kosteczki słuchowe jama bębenkowa

INTRODUCTION

Due to the widespread use of general anesthesia in otosurgical procedures, the functional outcomes of tympanoplasty are verified by patients and physicians as late as after complete healing of the middle ear. Good audiological outcomes are obtained in about 60% of patients regardless of the type of the implant or the technique used to perform the tympanoplasty [1, 2, 3]. In the remaining cases, potential hearing improvement may be achieved only following resurgery. The final outcome, however, is difficult to predict.

Intraoperative use of objective measurement methods could be an important factor facilitating the improvement in final functional outcomes and contributing to our knowledge of the principles of middle ear reconstruction. The objective of tympanoplastic surgeries consists in improving the air conduction level by removal of pathologically lesioned and/or superinfected tissues, reconstruction of tympanic membrane and ossicular chain and restoration of middle ear air cavities, particularly the tympanic cavity [4]. In cases of chronic otitis media, stable and without effusion, tympanoplasty procedures are carried out according to a single-stage protocol. In cases of intense inflammation accompanied by continuous effusion as well as in cases of cholesteatoma-related inflammations, the ear reconstruction strategy may consist of 2 stages. Conservative and radical ear surgeries without restoration of the tympanic membrane are becoming history as they are no longer performed at leading otosurgical centers. Thus, elective two-stage treatment of chronic otitis media consists of the first step involving removal of inflammatory lesions and reconstruction of the tympanic membrane, and the second stage consisting of ossiculoplasty being performed on the healed middle ear when the tympanic membrane is conserved and in stable location, as this ensures optimum condition for ossicular reconstruction.

Two categories of tympanoplastic surgeries may be identified [5, 6], with EAC postero-superior wall being lowered down (open techniques) or conserved (closed techniques). The latter are the procedures of choice, particularly in pediatric patients as they contribute to conservation of anatomical relationships between the structures of the middle ear and external auditory canal.

SURGICAL ACCESS AND TECHNIQUE ENABLING AUDIOLOGICAL MONITORING

When analyzing potential conditions for audiological monitoring in the course of tympanoplasty with ossicular chain reconstruction and the assessment of the efficiency of the middle ear conduction system, one may account for the possibility of acoustic stimulation within the EAC resulting in an electrophysiological response, preferably measured at a close distance (e.g. promontory, round window) or for possible visualization of ossicles for laser Doppler vibrometry (LDV) measurements. Both these methods are complimentary, as the presence of ossicular vibrations does not mean that an electrophysiological response has been triggered, the former being an immediate and the other a delayed response. Considering the above, patent and unchanged or slightly changed external auditory canal as well as functional tympanic membrane and ossicular chain are natural prerequisites for any intraoperative measurements. These conditions are best met in closed technique procedures. Optimum conditions are encountered when pathological lesions (cholesteatomatic otitis media) are removed and tympanic membrane is reconstructed at the first stage of the procedure. The second-look surgery may include ossicular implants being put into place from the mastoid process access by posterior tympanotomy and measurements being made with external auditory canal being used for acoustic air stimulation.

Somewhat more difficult measurement conditions are encountered in single-stage procedures. However, acoustic stimulation is still possible in these cases. Surgical technique should be adjusted so as to enable stable placement of the tympanic transplant with EAC skin incisions facilitating efficient placement of a microphone insert into the EAC (Fig. 2d, e).

To this end, a special middle ear access technique referred to as three-tunnel technique and a tympanic membrane reconstruction technique referred to as underlay/stretching technique have been developed.

The idea of the technique is that the graft is being placed as hide is being stretched onto a drum. This facilitates for intraoperative middle ear functional measurements being conducted with

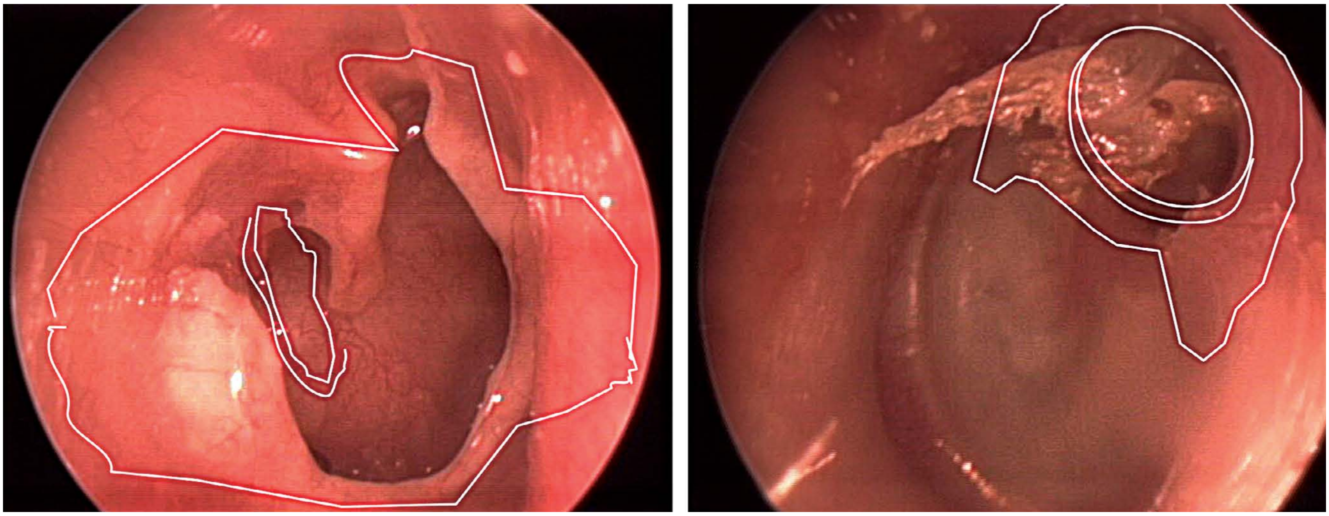


Fig. 1 a, b. Otoendoscopic presentation of ears with mesotympanic (a) and epitympanic perforation of the tympanic membrane (b). White lines indicate the range of fascial underlay in the underlay/stretching technique. (a) mesotympanic perforations: the place for a graft-reinforcing cartilage is marked in the posterior quadrant; (b) epitympanic perforations: the site for cartilage placement has been circled.

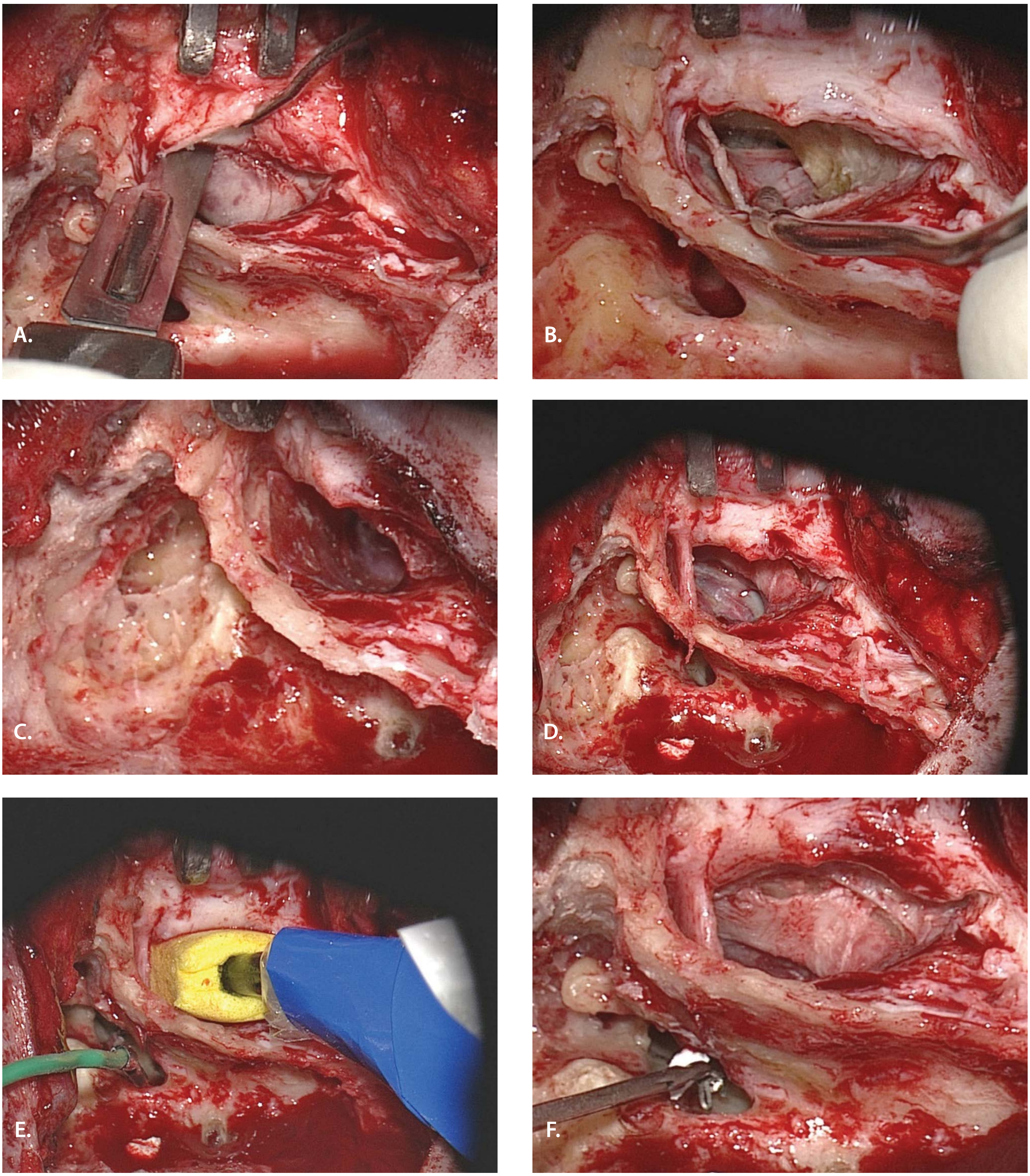
the tympanic graft being stretched so as to mimic the healed ear condition. Tympanic membrane reconstruction technique remains the same for single as well as dual-stage surgeries. The simultaneously placed and stabilized tympanic graft (Fig. 2c, 2d) remains in place throughout the healing phase provided no complications occur to disturb the process.

The graft is usually reinforced with cartilage at sites where secondary retraction pockets may be formed. After graft placement, its position is verified from posterior tympanotomy (1 tunnel). The same access is used for the placement of ossicular chain prosthesis (Fig. 2f). Thus, the final shape of ossicular prosthesis may be adjusted intraoperatively to the defect subject to reconstruction. Positions and parameters (length, weight) of ossicular prostheses are modified in the course of intraoperative surgeries so that optimum hearing improvement may be achieved.

The main elements of the three-tunnel technique for accessing the middle ear and the targeted structures include:

- retroauricular incision;
- antromastoidectomy with posterior tympanotomy (tunnel no. 1) – not necessary in some cases;
- first, horizontal incision of the posterior EAC wall skin ca. 3-5 below the external margin of the posterior bony EAC wall (Fig. 2a);
- second, horizontal incision of the anterior EAC wall ca. 2 mm below the first incision (Fig. 2a). Both incisions should be made within the part where EAC skin consists of all its parts (cartilaginous part). This facilitates safe performance of subsequent surgery stages without the risk of damage to the EAC skin and the placement of a sterile microphone insert for intraoperative acoustic stimulation. The first, posterior incision, is used for dissection of the posterior EAC wall skin and generation of the second tunnel for the checkup/cleansing of the posterior tympanic cavity, insertion of tympanic graft, and reconstruction of all kinds of mesotympanic defects. The second, anterior incision, is used for dissection of the anterior EAC wall, meatoplasty (straightening of EAC curvature), dissection of the anterior part of the tympanic ring and transsection of tympanic cavity lining above the auditory tube (Fig. 2b) as well as for stretching and stabilization of the tympanic graft. The stabilized tympanic graft may provide a scaffolding for the placement of cartilage onto the fascia followed by the placement of another fascial layer. This procedure is performed in children and other patients with clinical signs of auditory tube impairment (cleft palate).

Epitympanic defects are reconstructed using this approach after dissection of epitympanic skin and the tympanic membrane at upper manubrium (Fig. 1b). Epitympanum reconstruction is carried out using three layers (fascia-cartilage-fascia) placed using the underlay technique, with the first fascial layer being supported by the EAC bone and upper manubrium and the remaining layers being fitted to the epitympanic defect. The technique affords stable reconstruction and facilitates electrophysiological measurements being performed after microphone is placed within the EAC.



Ryc. 2. ?????????????????

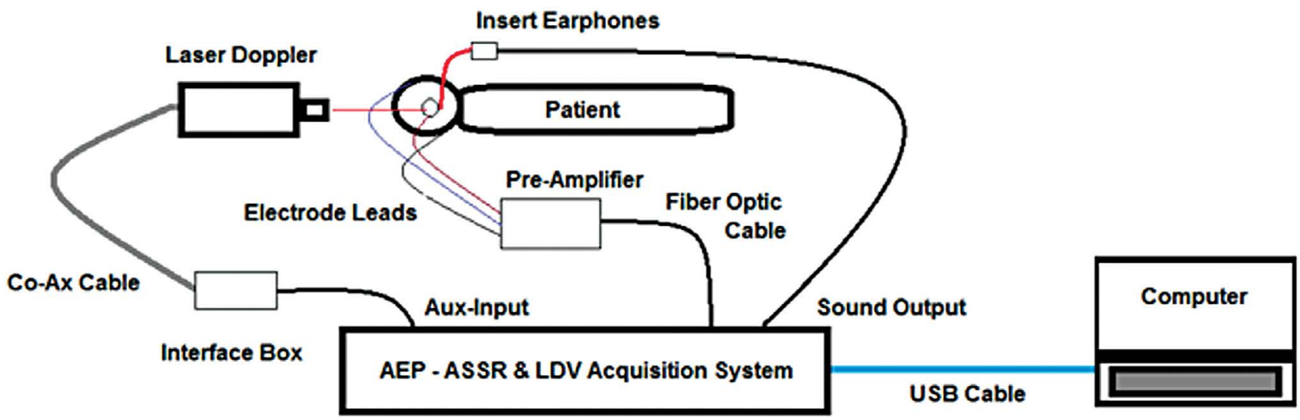


Fig. 3. Block diagram of the OssiMon LAIOM system including primary ASSR (Intelligent Hearing System) and LDV (Polytec) measurement devices.

METHODOLOGY OF INTRAOPERATIVE ASSR AND LDV MEASUREMENTS USING THE OSSIMON LAIOM SYSTEM

Overview of OssiMon LAIOM software

OssiMon LAIOM (Laser ASSR Intraoperative Ossiculoplasty Monitoring) software is a comprehensive tool for intraoperative audiological monitoring including electrophysiological simultaneous auditory steady-state response (ASSR) measurements and laser Doppler vibrometry (LDV) measurements of ossicular vibrations.

OssiMon LAIOM may be used in patients of all ages. The software is intended for use by trained medical professionals (physicians, audiophonologists) in operating theaters in the course of tympanoplasty with ossicular chain reconstruction as well as in other appropriate settings, i.e. for research purposes. Currently, OssiMon LAIOM is designed to operate with the Intelligent Hearing Systems IHS USB Box + SmartEP interface and software (Intelligent Hearing Systems, Corp. Miami, Florida, USA) as an additional measurement model. LDV measurements are conducted using a single-point Polytec laser (Fig. 3).

OssiMon LAIOM software facilitates simultaneous performance of ASSR and LDV measurements. In order to carry out ASSR measurement, the user should appropriately attach needle electrodes to the patient's head: the positive (+) electrode is placed under the skin at the apex of the patient's head while the negative electrode (–) is placed in the round window niche region of the target middle ear and the ground electrode is placed under the forehead skin medially on the hairline. Instead of needle electrode, an electrode tip shaped to match the tympanic sinus may be used as the negative (–) electrode. OssiMon LAIOM software generates an auditory stimulus consisting of four measurement frequencies of 500, 1000, 2000 and 4000 Hz at the sampling rate of 20 kHz and repeated with the respective frequencies of 77, 85, 93, and 101 Hz for the left ear (in left ear surgeries) or 79, 87, 95, and 103 Hz for the right ear (in right ear surgeries). The intensity of the acoustic stimulus is reduced in 5-10 dB intervals from the level of 80 dB SPL down to the hearing threshold. The measurement filter is set for the range of 30-300 Hz while the narrow band filter used to filter off the surrounding electrical network noise from the measurement signal is set at 50 Hz. Signal gain is set at 100 k for all measurements.

In order to carry out the LDV measurement, laser beam should be directed through the posterior tympanotomy opening onto a small piece of reflective foil (1.5 x 1.5 mm) placed within the reconstructed ossicular chain, more specifically: a) on the stapes bone head in malleus-stapes assembly (MSA) or short columella (SC) ossiculoplasty; b) directly on the branch of the ossicular implant in malleus-footplate assembly (MFA) or long columella (LC) ossiculoplasty. A small fragment of reflective foil is placed as vertically as possible so that it is possibly most perpendicular to the laser beam. Perpendicular incidence of laser beam is required for optimization of the quality of the measurements of the reconstructed ossicular chain vibrations. LDV measurements are carried out simultaneously to ASSR measurements using the same interface at the sampling rate of 20 kHz.

OssiMon LAIOM, simultaneous measurements of ASSR and LDV are possible thanks to signals from each measurement devices being averaged in a synchronized manner. The results are regularly updated on the OssiMon LAIOM system screen (Fig. 3).

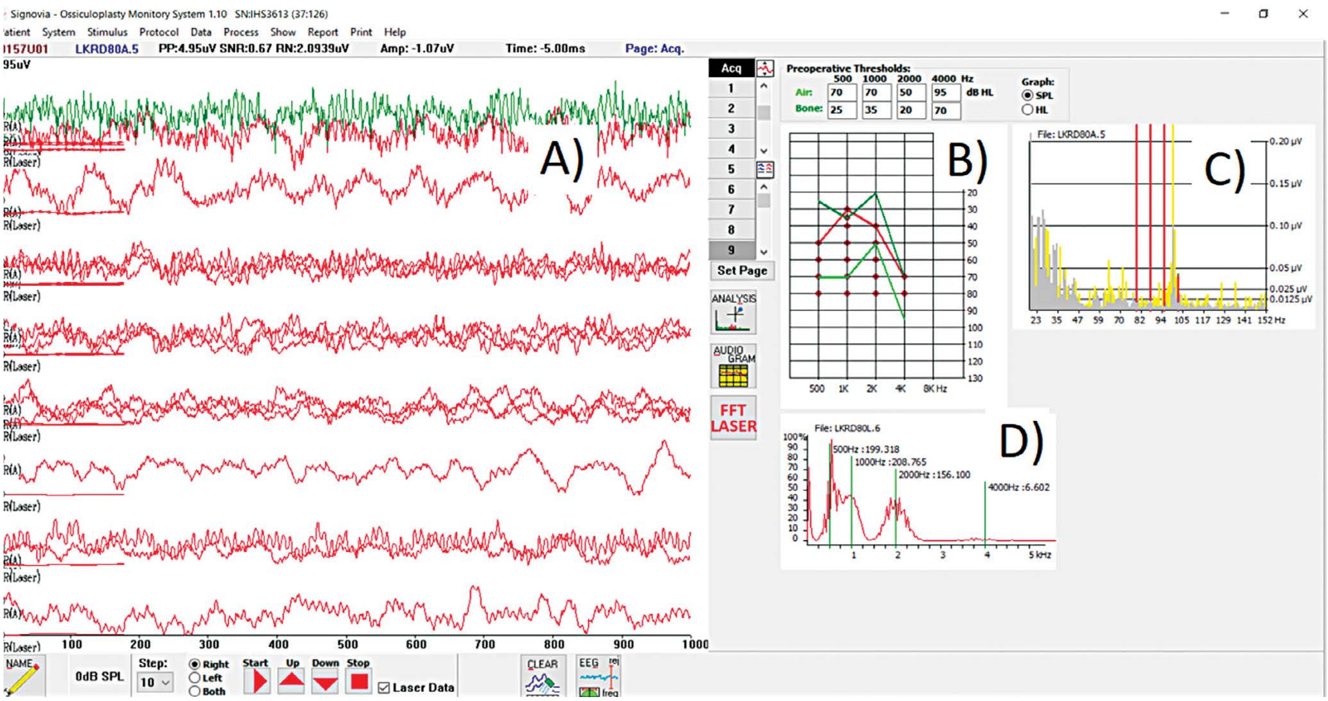


Fig. 4. Example results of intraoperative measurements obtained using OssiMon LAIOM software. OssiMon LAIOM software presents the results on the ASSR and LDV monitoring system screen (IHS USB Box + SmartEP). A) real-time data acquisition window; B) window with the audiogram generated and updated during the measurement. Green lines remain stable throughout the measurement to show tone audiometry results obtained in the patient before the procedure and entered into the OssiMon LAIOM software before the surgery (the dark green line corresponds to bone conduction hearing thresholds while the light green line corresponds to air conduction hearing thresholds) as a reference for cochlear reserve closure assessment. Red line presents the ASSR hearing threshold obtained in the ongoing and updated measurement; C) ASSR being continuously updated in the course of the measurements and presented as a response signal amplitude vs. frequency plot; D) window with LDV results updated in the course of the measurements.

Thanks to the OssiMon LAIOM software, intraoperative ASSR measurements can be acquired to assess hearing responses for acoustic stimuli of predefined intensity as quickly as within 20-30 seconds while ossicular LDV measurements take as little as several seconds. In addition, the results of the integrated ASSR and LDV measurements are analyzed and assessed automatically in the course of the measurement. Current results are presented on the screen and updated every several seconds (Fig. 4).

Thanks to the results of integrated ASSR-LDV measurements being available for immediate use, individual interpretation differences which might arise should the results be assessed and analyzed by the individual carrying out the intraoperative examination can be eliminated.

Intraoperative measurements obtained using the OssiMon LAIOM software facilitate optimum reconstruction of ossicular chain in the course of a tympanoplasty procedure as well as optimum placement or replacement of ossicular prosthesis in the course of the same procedure. The results of the OssiMon LAIOM measurements can be used to verify the efficacy of ossiculoplasty by assessing the hearing threshold and cochlear reserve closure prior to completion of the procedure [7].

DISCUSSION

Few sites and research groups are capable of performing intraoperative monitoring of hearing ability during ear surgeries.

Electrophysiological measurements were used for the first time to improve hearing in the course of otosclerosis (stapedectomy) surgery by JJ Wazen et al. in 1997 [8]. The authors were able to observe good correlation between the hearing level assessed by electrocochleography following acoustic stimulation and postoperative outcomes. However, their system was not suitable for wider use due to the long duration of hearing assessment and lack of appropriated surgical technique. Other possibilities were offered by the measurements of laser light interference – laser Doppler vibrometry – facilitating the assessment of ossicular vibrations and introduced in experimental and clinical studies by RL Goode et al. in 1993 [9]. Despite numerous reference experimental studies being available, the researchers focused on the use of in vivo LDV measurements for the diagnostics of sound conduction system disorders rather than on practical applicability of the technique for intraoperative assessment of hearing improvement.

The most recent solution for intraoperative assessment of hearing, proposed by Zahnert et al. in 2016, consists in an electromagnetic stimulation system [10]. However, this is subjective evaluation being performed by the surgeon, and thus essentially similar to intraoperative evaluation during the surgery. In this system, the surgeon is able to assess the quality of hearing impairment by listening to sound signals obtained from the processing of responses to electromagnetic stimulation of the ossicular chain subject to reconstruction procedure. Main disadvantages of the solution is that the assessment is qualitative in nature and that the sound being processed by the electromagnetic system does not have to reflect actual hearing improvement.

The system proposed by the researchers from Warsaw is currently the only solution that can be actually used in an intraoperative setting for objective dual technique (LDV and ASSR) assessment, as it has been adapted for operating theater requirements and its efficacy has been confirmed in the largest number of patients.

SUMMARY

Intraoperative audiometric monitoring is possible in dual- or single-stage ossicular reconstruction in the course of closed--type tympanoplasties performed from retroauricular access with antromastoidectomy and posterior tympanotomy.

Electrophysiological methods (ASSR) and ossicular vibration measurement methods (LDV) may be used for intraoperative assessment of middle ear function.

The OssiMon LAIOM software makes simultaneous use of both of these methods for intraoperative measurement of middle ear function and is well suited for use in clinical practice.

References

1. House J.W., Teufert K.B.: Extrusion rates and hearing results in ossicular 1reconstruction. Otolaryngol Head Neck Surg. 2001 Sep; 125 (3): 135–41.
2. Goldenberg R.A., Driver M.: Long-term results with hydroxylapatite middle ear implants. Otolaryngol Head Neck Surg. 2000 May; 122 (5): 635–42.
3. Dalchow C.V., Grün D., Stupp H.F.: Reconstruction of the ossicular chain with titanium implants. Otolaryngol Head Neck Surg. 2001 Dec; 125 (6): 628–30.
4. Wullstein H.: The restoration of the function of the middle ear, in chronić otitis media. Ann Otol Rhinol Laryngol. 1956 Dec; 65 (4): 1021–41.
5. Artuso A., di Nardo W., De Corso E., Marchese M.R., Quaranta N.: Canal wall down tympanoplasty surgery with or without ossiculoplasty in cholesteatoma: hearing results. Acta Otorhinolaryngol Ital. 2004 Feb; 24 (1): 2–7.
6. Ucar S., Iseri M., Ozturk M.: Evaluation of functional results of CWD surgery with ossicular replacement prosthesis due to cholesteatoma using computed tomography. Eur Arch Otorhinolaryngol. 2014 Sep; 271 (9): 2393–400.
7. Niemczyk K., Morawski K., Delgado R., Bruzgielewicz A., Lachowska M.: Objective assessment of hearing during second stage of tympanoplasty--surgical technique and measurement methodology presented in ten patients. Clin Otolaryngol. 2018 Feb; 43 (1): 347–352.
8. Wazen J.J., Emerson R., Foyt D.: Intra-operative electrocochleography in stapedectomy and ossicular reconstruction. Am J Otol. 1997 Nov; 18 (6): 707–13.
9. Goode R.L., Ball G., Nishihara S.: Measurement of umbo vibration in human subjects--method and possible clinical applications. Am J Otol. 1993 May; 14 (3): 247–51.
10. Zahnert T., Metasch M.L., Seidler H., Bornitz M., Lasurashvili N., Neudert M.: A New Intraoperative Real-time Monitoring System for Reconstructive Middle Ear Surgery: An Experimental and Clinical Feasibility Study. Otol Neurotol. 2016 Dec; 37 (10): 1601–16.

Word count: 2490 Tables: – Figures: 4 References: 10

Access the article online: DOI: 10.5604/01.3001.0012.6803 Table of content: https://otorhinolaryngologypl.com/issue/11380

Corresponding author: prof. dr hab. med. Kazimierz Niemczyk; Katedra i Klinika Otolaryngologii, Warszawski Uniwersytet Medyczny; e-mail: kniemczyk@wum.edu.pl

Competing interests: The authors declare that they have no competing interests.

Cite this article as: Niemczyk K., Morawski K., Delgado R., Małkowska M., Bartoszewicz R., Sokołowski J., Lachowska M.: Intraoperative hearing evaluation during tympanoplasty – surgical technique and measurement method using OssiMon LAIOM system; Pol Otorhino Rev 2018: 7(3): 13-20