The Journal of International Advanced Otology

J Int Adv Otol 2021; 17(1): 9–12 • DOI: 10.5152/iao.2020.4876

Original Article

Wideband Absorbance Outcomes of Cochlear Implantation: A Comparative Clinical Study

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Cite this article as: Orhan KS, Çelik M, Polat B, Dikici T, Güldiken Y. Wideband Absorbance Outcomes of Cochlear Implantation: A Comparative Clinical Study. J Int Adv Otol 2021; 17(1): 9-12.

OBJECTIVES: Wideband tympanometry (WBT) measurements show sensitivity to trends in external ear canal/middle ear maturation and changes in middle ear status as a result of different types of dysfunction. This study aims to determine the effects of cochlear implantation (CI) on middle ear status.

MATERIALS and METHODS: This is a prospective comparative clinical study that has been done in a tertiary referral center. The patients who underwent unilateral cochlear implantation were included in the study. All the participants were under 18 years of age and had congenital bilateral profound sensorineural hearing loss (SNHL). WBT measurements of implanted ears were calculated and compared to those of non-implanted ears (control group) in the same patient group. The differences in these measurements were subjected to statistical analyses.

RESULTS: A total of 48 patients (96 ears) who underwent unilateral CI were included in the study. Our study revealed that significant reductions in the average absorbance ratios occurred at all measured frequencies and that the average resonance frequency increased more significantly in the implanted ears compared with those of control group ($p<0.001$). The difference in the average peak pressure was not significant among two groups. ($p=0.211$)

CONCLUSION: This study shows that the average absorbance ratio decreases and average resonance frequency increases after cochlear implantation. These findings may be related to increased stiffness in middle and inner ear system. Future studies are needed for more detailed information and recommendations on this topic.

KEYWORDS: Cochlear implantation, acoustic impedance tests, middle ear, wideband tympanogram

INTRODUCTION

Cochlear implant (CI) is a surgically implanted electronic device that restores hearing in patients with profound or severe hearing loss who cannot benefit from conventional hearing devices. Ordinary surgical procedure for CI consists of mastoidectomy with facial recess approach or posterior tympanotomy [1-3]. In this technique, the electrode array is simply inserted into the scala tympani in conventional manner via posterior tympanotomy.

There is lack of information on the effects of cochlear implantation on the mechanics of middle and inner ear. The injury to the hair cells and displacement pattern of the ossicles have been reported after cochlear implantation [4, 5]. In addition, Donnelly et al. have advocated that mechanics of the middle ear is affected by the vibration pattern of the stapes footplate [5].

One of the common evaluation procedures is tympanometry, which provides quantitative information on the function of structures and distinguishes between middle ear disorders [6]. Standard tympanometry with single probe tone frequency (226 Hz) is an effective measure of the middle ear function in adults and children; however, it is not recommended for infants aged less than 7 months, due to its low sensitivity in identifying the middle ear pathology [7, 8]. High probe frequency (1000 Hz) may be more sensitive to the middle ear disorders in infants compared with the frequency of 226 Hz, since the middle ear is more of a mass-dominated rather than a stiffness-dominated system [9, 10].

Wideband tympanometry (WBT) is a revolutionary technique to assess middle ear function for the clinician to provide more diagnostic information without additional effort. Measuring tympanograms for multiple frequencies at once provides both conventional tympanograms as well as new information that can be retrieved from the absorbance graph, resonance frequency, or wideband

This study was presented at the 15th Symposium on Cochlear Implant in Children, July 26-29, 2017, San Francisco, California, USA.

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Submitted: 05.09.2019 • **Accepted:** 05.26.2020
Available online at www.advancedotology.org

averaged tympanogram [11, 12]. WBT uses a broadband click that provides measurements at frequencies from 226 Hz to 8000 Hz. It takes similar time to perform as in a standard tympanogram. However, during this time, clinical information acquired is more detailed compared with that obtained by testing 226 Hz or 1000 Hz alone [11, 13-15].

In the existing literature, there is no available information about the WBT findings in patients who underwent cochlear implantation. This study aims to investigate the effects of cochlear implantation on the middle and inner ear status using wideband tympanometry.

MATERIALS AND METHODS

Patients who underwent unilateral cochlear implantation at least 1 year ago were included in this study. All participants were under 18 years of age and had bilateral congenital profound sensorineural hearing loss (SNHL). Patients who had an abnormal, asymmetric anatomy of the temporal bone or bilateral implantations were excluded from the study. Otoscopic examination was conducted using an otomicroscope to document the status of the ear canal and tympanic membrane to exclude cases with middle or external ear disorders (i.e., serous otitis media, tympanic membrane perforation, and exostosis) and impacted external ear wax. Each measurement of implanted ears was calculated and compared to those of non-implanted ears (control group) in the same patient group. The patients were informed about the study in a face-to-face interview with their parents, and informed consent were obtained from them. The study was approved by local institutional board.

The WBT findings were obtained using the Interacoustics Titan version 3.1 (IMP440, Denmark). Before the measurements, the WBT device was calibrated according to IEC 60645-5/ANSI S3.39. The measurements of WBT were performed at frequencies between 226 Hz and 8000 Hz. Resonance frequency, peak pressure, and absorbance at ambient and peak tympanic pressure for each frequency were obtained.

According to a protocol recommended by the manufacturer, the WBT system was calibrated daily. Pediatric size insert foam ear tip (ER10C-14B, ER10C-04, or ER10C-05) attached to the ER-10C probe (Etymotic Research, Elk Grove Village, Illinois)) was used to minimize acoustic leaks with two outputs (transducers) and an input (microphone). Instructions were given to children's parents to sit quietly for 1 minute during the test period. Absorbance measurements at ambient and peak tympanic pressure were obtained by recording acoustic responses to clicks, presented at 55 dB SPL and at a rate of 12.5/s to each ear. Absorbance was measured from 226 Hz to 8000 Hz as the ear canal pressure was swept at 100 daPa/s from +200 to − 400 daPa while the probe frequency was held constant (sweep pressure procedure).

In addition, absorbance values were compared at the following frequency ranges: 226-1000 Hz, 1000-2000 Hz, 2000-4000 Hz, and 4000-8000 Hz. OtoAccess version 1.3.0.0 (Interacoustics, Assens, Denmark) data recording software was used to record the data and calculate the results.

Statistical Analysis

Two groups were analyzed by unpaired student's t-test using the Statistical Package for the Social Sciences (SPSS) version 21 (IBM Corp.; Armonk, NY, USA). A p value smaller than 0.05 ($p<0.05$) was considered statistically significant.

Table 1. Demographic data of the patients

	No. of Patients
Gender	
Female	22 (45.9)
Male	26 (51.4)
Implant side	
Right	42 (87.5)
Left	6 (12.5)
Brand of the Implants	
Cochlear	35 (73)
Med-El	9 (18.75)
Advanced Bionics	4 (8.25)

RESULTS

A total of 48 patients (96 ears) who underwent unilateral cochlear implantation were included in this study. Twenty-six (51.4%) of the patients were male, 22 (45.9%) were female, and mean age was 8.2±4.4 years. Forty-two of the patients were implanted in the right ear side and 6 in the left. Mean follow-up period was 3.4±2, and 1 years postoperatively (Table 1).

The average resonance frequency was 846.7±333.8 Hz for implanted ears and 815.05± 249.7 Hz for non-implanted ears. This difference was statistically significant ($p<0.001$).

The average peak pressures (daPa) of the power absorbance tympanogram for implanted and control ears were -31.56 DaPa and -34.61 DaPa, respectively, and this difference was not statistically significant. ($p=0.211$)

The average absorbance ratios of implanted ear and control were 0.476±0.156 and 0.555±0.155, respectively (Figure 1). In addition, average absorbance ratios at peak tympanic pressure for implanted ears at 226-1000 Hz, 1000-2000 Hz, 2000-4000 Hz, and 4000-8000 Hz were 0.250±0.117; 0.518±0.241; 0.611± 0.206, and 0.524±0.230, respectively. In the control group, it was 0.341±0.146, 0.566±0.184, 0.711±0.129 and 0.600±0.197, respectively. Both the common average ratios and the average ratios of specific frequency ranges for the two groups were compared, and the average absorbance ratio of the implanted ears were statistically significantly low ($p<0.001$) (Table 2).

DISCUSSION

In this study, effects of CI on middle ear function were investigated with WBT. Middle ear functions are known by various terms, including wideband middle ear impedance [16], wideband reflectance [17], and wideband middle ear power [18]. Frequencies, ranging from 62 Hz to 13,000 Hz depending on the equipment and calibration method, have been used for this purpose [19]. WBT provides research and clinical purposes for acoustic functioning of the normal middle ear in adults, infants, older children, neonates, and ethnic groups [7, 11, 18-22]. Besides, it allows more detailed information than standard tympano-

Table 2. Wideband tympanometric results

	Implanted ear group	Control group	p
Mean average resonance frequency (Hz)	846.7±333.8	815.05±249.7	p<0.001
Mean average peak pressure (daPa)	-31.56	-34.61	p=0.211
Mean average absorbance ratio (Hz)	0.476±0.156	0.555±0.155	p<0.001
226-1000 Hz	0.250±0.117	0.341±0.146	
1000-2000 Hz	0.518±0.241	0,566±0.184	
2000-4000 Hz	0.611±0.206	0.711±0.129	
4000-8000 Hz	0.524±0.230	0.600±0.197	

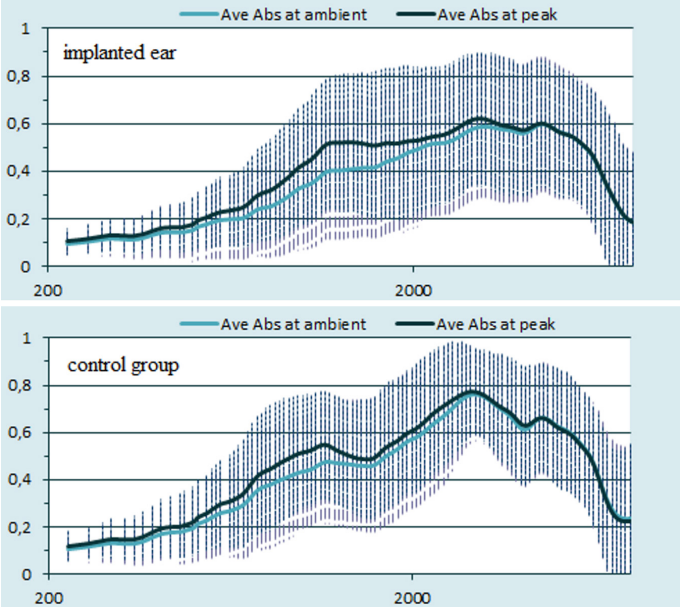

Figure 1. Average absorbance ratios in implanted ear and control group. (Ave Abs: Average Absorbance)

gram for middle ear disorders [13-15, 23].

Sound energy is absorbed by various structures in the middle ear such as the tympanic membrane, ligaments of the ossicular chain, and mastoid air cells [24]. Therefore, differences in the composition of these structures may also cause differences in middle ear measurements. Previous studies of WBT have typically reported measurements in terms of energy reflectance, not power absorbance [12, 17, 22, 23]. For instance, at the lowest and highest frequencies, the power absorbance is low whereas the energy reflectance is high. However, Allen et al. have suggested that sound absorbance ratio is more easily interpreted as it is the absorbed power that will in turn determine the sensitivity of the ear [18]. Therefore, power absorbance was selected for analysis in our study.

In standard procedure, cortical mastoidectomy with posterior tympanotomy is performed for cochlear implantations. Afterwards, electrode array is inserted to scala tympani via round window passthrough posterior tympanotomy. It is apparent that middle ear anatomy may change following this technique. Some of the anatomical changes are as follows: increased volume of aerated system including middle ear and mastoid cavity that become one cavity by posterior tympanotomy, obliterated the round window by electrode array, and scar formation in middle as well as inner ear. Therefore, some of these outcomes can explain the low absorbance ratios of the implanted ears compared with those of the control group.

Many studies have shown that increased stiffness in the middle ear system increases power reflectance and decreases absorbance at the frequencies lower than 2000 Hz [14, 25, 26]. Studies on power reflectance have focused on stapes fixation. Shahnaz et al investigated patterns of power reflectance in otosclerotic ears and compared these patterns of power reflectance following stapes surgery. A sharp and deep reduction in power reflectance between 700 and 1000 Hz was the most obvious change after stapes surgery. Furthermore, they found a mild increase in power reflectance between 2000 and 4000 Hz following stapes surgery. They advocated that the severing of the annular ligament resulted in decreased stiffness of the middle ear post-surgery [14]. Moreover, a human cadaveric study has shown that disarticulation of the ossicular chain creates a low frequency notch in the energy reflectance that recovers with the repair of disarticulation [13]. In this study, there may be some explanations for low absorbance values in operated ears. Insertion of electrode into the scala tympani may disrupt the traveling wave of basilar membrane. Obliteration of the round window prohibits movement of fluid in cochlea due to restricted round membranes bulging out. In addition, posterior tympanotomy or drilling round window's niche may result in scar formation around ossicles. Both widespread stiffness and insertion of electrode array may explain the decrease in the absorbance ratio over the entire frequency range.

In this study, we found that the average resonance frequency was 846.7±333.8 Hz in implanted ears compared to 815.05±249.7 Hz in the control group. The resonance frequency corresponds to the frequency at which mass and stiffness contribute equally to the middle ear admittance and the phase makes zero [27]. Identifying the resonance frequency can be useful in the diagnosis of ossicular chain abnormalities. For instance, the middle ear resonance frequency tends to shift to higher frequencies with abnormal stiffness dominating pathologies such as otosclerosis and shift to lower frequencies with mass such as ossicular chain discontinuities [13, 14]. Consequently, these results support the hypothesis that cochlear implantation causes increased stiffness in the middle ear system.

CONCLUSION

This is the first study to evaluate to effect of CI surgery on middle ears status by using WBT, which is a revolutionary technique to as-

sess middle ear function. This study shows that average absorbance ratio at all measured frequencies decreases and average resonance frequency increases after cochlear implantation. These findings may be related to increased stiffness in middle and inner ear system. Future studies are needed with participants from different age groups to better understand the changing middle ear status after CI.

Ethics Committee Approval: Ethics committee approval was received for this study from the Research Ethics Committee of Istanbul University School of Medicine on the 12th May 2017 (Ref-2017-511).

Informed Consent: Written informed consent was obtained from the participants' guardians.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – K.SO., M.Ç.; Design – K.S.O.; Supervision – Y.G., K.S.O., B.P.; Resource – K.S.O., M.Ç., T.D.; Materials – K.S.O., M.Ç., B.P.; Data Collection and/or Processing –K.S.O., M.Ç., T.D.; Analysis and/or Interpretation – K.S.O., M.Ç., B.P.; Literature Search – K.S.O., M.Ç.; Writing – K.S.O., M.Ç., B.P.; Critical Reviews – K.S.O., M.Ç., Y.G.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: This study was supported by Istanbul University, Research Fund. Project No. 3507-59407.

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