Archives of Materials Science and Engineering

Volume 42
Issue 2
April 2010
Pages 104-110

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

Development of cartilage conduction hearing aid

H. Hosoi [a], S. Yanai [a,*], T. Nishimura [a], T. Sakaguchi [a], T. Iwakura [b], K. Yoshino [c]

[a] Department of Otorhinolaryngology, Nara Medical University, Kashihara, Nara 634-8522, Japan
[b] Department of Audiological Engineering, Rion Co., Ltd, 3-20-41 Higashi-motomachi, Kokubunji, Tokyo 185-8533, Japan
[c] Development Department, Piezoelectric Device Division, NEC/TOKIN Co., Ltd, 7-1-1 Asahi-Cho, Shiroishi, Miyagi 989-0223, Japan
* Corresponding author: E-mail address: yanai@naramed-u.ac.jp

Received 13.02.2010; published in revised form 01.04.2010

ABSTRACT

Purpose: The potential demand for hearing aids is increasing in accordance with aging of populations in many developed countries. Because certain patients cannot use air conduction hearing aids, they usually use bone conduction hearing aids. However, bone does not transmit sound as efficiently as air, and bone conduction hearing aids require surgery (bone anchored hearing aid) or great pressure to the skull. The first purpose of this study is to examine the efficacy of a new sound conduction pathway via the cartilage. The second purpose is to develop a hearing aid with a cartilage conduction transducer for patients who cannot use regular air conduction hearing aids.

Design/methodology/approach: We examined the hearing ability of a patient with atresia of both external auditory meatuses via three kinds of conduction pathways (air, bone, and cartilage). After the best position for the cartilage conduction transducer was found, audiometric evaluation was performed for his left ear with an insertion earphone (air conduction), a bone conduction transducer, and a cartilage conduction transducer. Then we made a new hearing aid using cartilage conduction and got subjective data from the patients.

Findings: The tragal cartilage was the best position for the cartilage conduction transducer. The patient's mean hearing levels were 58.3 dBHL, 6.7 dBHL, and 3.3 dBHL for air conduction, bone conduction, and cartilage conduction respectively. The hearing ability of the patients obtained from the cartilage conduction hearing aid was comparable to those from the bone conduction hearing aid.

Practical implications: Hearing levels using cartilage conduction are very similar to those via bone conduction. Cartilage conduction hearing aids may overcome the practical disadvantages of bone conduction hearing aids such as pain and the need for surgery.

Originality/value: We have clarified the efficacy of the cartilage conduction pathway and developed a prototype 'cartilage conduction hearing aid', which is the first hearing aid to use sound transmission via cartilage.

Keywords: Industrial management and organization; Safety and health management; Hearing aid; Sound conduction via tragal cartilage

Reference to this paper should be given in the following way:

H. Hosoi, S. Yanai, T. Nishimura, T. Sakaguchi, T. Iwakura, K. Yoshino, Development of cartilage conduction hearing aid, Archives of Materials Science and Engineering 42/2 (2010) 104-110.

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

It is well known that physical function deteriorates with increasing age [1], and hearing ability is no exception [2, 3]. A hearing aid is usually supplied to elderly people with a hearing impairment. Given the aging of populations in many developed countries, the potential demand for hearing aids is increasing. Since the first appearance of digital hearing aids in 1987, there has been an explosion in the number of digital hearing aids on the market. The digital signal processing which is applied for the digital hearing aid improves noise suppression without deterioration of the auditory signal, acoustic feedback control, and word intelligibility, etc.[4-6]. The development of digital hearing aids is boon to the patients with hearing impairment.

Although such developments in digital hearing aids are expected to result in the better communication in patients with hearing impairment, patients who suffer from specific pathological conditions such as otorrhea or atresia of the external auditory meatus cannot benefit from common air conduction digital hearing aids, since the air conduction earphone cannot be used.

For patients with such pathological conditions, bone conduction hearing aids have been widely used [7, 8]. The bone conduction hearing aid also amplifies sounds but the sounds don't pass into the external auditory canal, instead the sounds are conducted to the bone of the skull. To transmit the sound to the skull, the bone conduction transducer should be positioned on the cranial bone at the retroauricular area. In the bone conduction hearing aid, the audio signal is converted into mechanical vibration and it is conducted into the inner-ear via the cranial bone.

The bone conduction hearing aid can be used by the patients with pathological conditions in their external auditory canal, however, the transmission efficacy of acoustic information is low because it relies on the vibration of the bone. In addition, despite fixation of bone conduction transducer is essential for comfortable use, an ideal method for fixation of the transducer has not yet been determined. And because the bone conduction transducer has to be strongly pressed on the skull for good transmission efficacy, many patients complain of pain and give up extended use. Since such problems are fatal for bone conduction hearing aids, bone anchored hearing aid (BAHA) was developed [9] for conductive and mixed hearing loss in 1977. The BAHA consists of two parts: a titanium implant with an external abutment, and a detachable sound processor. The sound processor transmits sound vibrations through the external abutment to the titanium implant. The vibrating implant sets up vibrations within the skull and inner ear, then finally stimulate the hair cells of the inner ear.

Although it can partially overcome the disadvantages of bone conduction hearing aids, there still remain several problems [10]. For example, to wear a BAHA, a surgical operation is needed to embed a titanium implant in the skull, which can introduce infection since a part of the implant is appeared in the air after the surgery. In addition, since the BAHA relies on bone conduction, the enough binaural hearing effect cannot be obtained.

Based on these backgrounds, we selected a piezoelectric transducer among several transducers [11-15] as the best transducer to solve these problems and effectively transmit auditory stimuli in hearing aids. Since we consider that auditory stimuli are transmitted via the cartilage of the tragus in this transducer, we call this as 'cartilage conduction'. In this study, we first examined the efficacy of sound transmission via cartilage conduction. Second, we developed a hearing aid using a cartilage conduction transducer for patients who cannot use regular air conduction hearing aids.

2. Materials and methods

2.1. Participant

An 11-years old patient with atresia of both external auditory canals participated in this study.

The patient's right ear was completely imperforated, but there was a shallow recess at the opening of the left external auditory canal (Figure 1).

Fig. 1. Appearance of the opening of the external auditory canal in this case. There is only a shallow recess

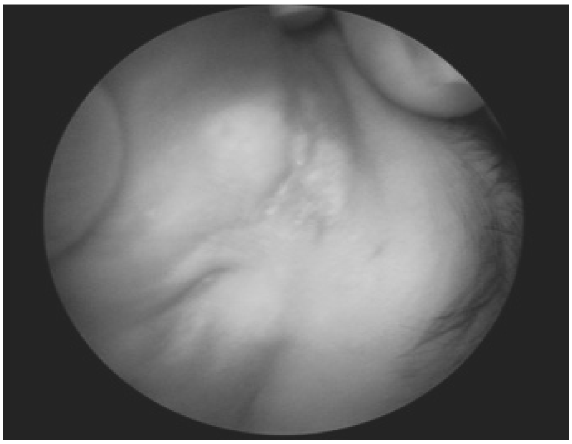

Fig. 2. Retroauricular area of the patient in this study. Since this patient has used a bone conduction hearing aid, a cave derived from the strong and lasting pressure of the bone conduction transducer was observed

Since a recess is needed to measure the hearing ability via air conduction, all measurements were performed on his left ear.

As this patient was diagnosed with moderate conductive hearing loss more than 10 years ago, he has used a bone conduction hearing aid. Since the bone conduction transducer requires strong pressure on the skull, this patient has complained of pain and annoyance with bone conduction hearing aid. In fact, a small collapse was observed at the spot where the bone conduction transducer was usually fixed (Figure 2).

2.2. Apparatus

The transducers for cartilage conduction were made up of the piezoelectric bimorph and covering material. The architecture of the transducer and its frequency-specific traits by several kinds of covering material are shown in Figure 3 and Figure 4, respectively. Covering materials used in the measurement is shown in Table 1.

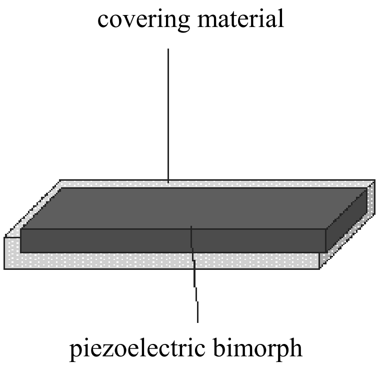

Fig. 3. Architecture of the transducer

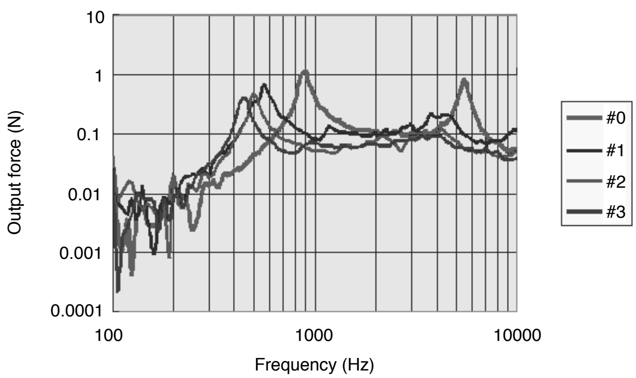

Fig. 4. Frequency-specific traits of transducer. #0 indicates that covering material was not used

They revealed that covering materials inhibit frequency-dependent changes in output force by controlling the secondary resonance point at 5.5 kHz, and relatively flat output force across frequencies could be obtained. And, it is able to control the frequency of primary resonance and obtain appropriate traits by changing the covering material.

Table 1.
Elastic modulus and thickness of covering materials used in the measurement

	Covering material	Elastic modulus Y [GPa]	Thickness of covering material Tc [mm]
#0	-	-	-
#1	Silicone rubber A	0.0035	1.3
#2	Silicone rubber B	0.0035	2
#3	Silicone rubber C	0.0012	1.3

According to the measurement of the frequency-specific traits of the transducer, it became clear that the acoustic traits are controllable by changing the thickness or elastic modulus of covering material. Therefore, developed transducers are able to remodel for several applications by changing the covering material or its form. Figure 5 shows the prototype of organic-material-covered-transducers that are intended to be used in the hearing aids.

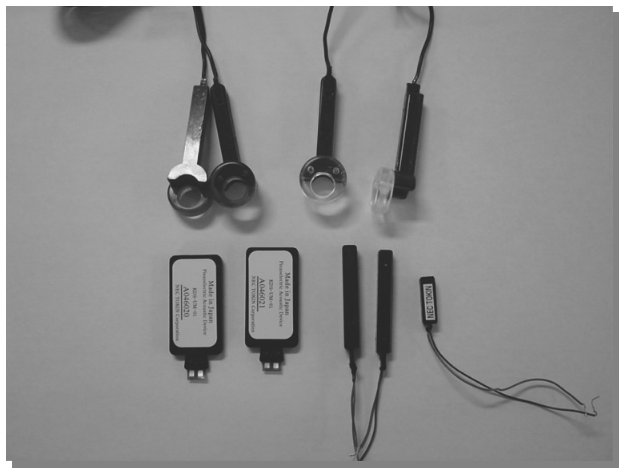

Fig. 5. Prototype of organic-material-covered-transducers aimed for the hearing aids

Among several prototypes of transducers, the acoustic traits of two transducers (KDS-UM-01 and KDS-UM-05) were measured with artificial mastoid (Figure 6). Both transducers contain piezoelectric bimorph, of which electrostatic capacitance between negative and positive terminals are 200 nF. Numbers of piezoelectric bimorph are six and four for KDS-UM-01 and KDS-UM-05, respectively. Our measurement showed that the acoustical output of low frequencies below 1 kHz is stronger in KS-UM-01 than in KS-UM-05, which is thought to be caused by the differences in the numbers of piezoelectric bimorphs

An audiometer (AA-7A; Rion, Inc., Tokyo, Japan) was used to measure the hearing ability of the patient. For air conduction, an insert earphone (Cabot Safety Corporation, Indianapolis, IN) was used. The earphone was calibrated to conform with the International Organization for Standardization (ISO) 389-2 before the measurement. For bone conduction, a bone conduction transducer (BR-41; Rion, Inc), which is an attachment of the audiometer, was used. This bone conduction transducer also conformed to the ISO 389-3. For cartilage conduction, a selected piezoelectric transducer was used (Figure 7; hereafter called the 'cartilage conduction transducer').

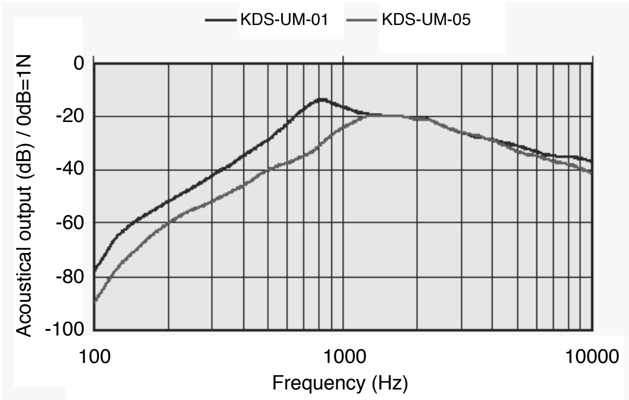

Fig. 6. Acoustic traits of transducers measured with artificial mastoid

Fig. 7. Piezoelectric transducer used in this study

2.3. Procedure

In order to compare three kinds of thresholds of the participant on the same scale, average hearing thresholds for three pathways were obtained from normal hearing subjects.

Since the right external auditory canal was completely closed, the data from the left ear is presented. After measurement of air and bone conduction, the cartilage transducer was softly attached to the patient's left tragus (Figure 8) and the cartilage conduction threshold was measured. The tragus was found to be the best position for sound transmission via a cartilage conduction transducer.

In advance of the experiments, he was provided written consent after being informed the nature of the experimental procedure and purpose of this study. All procedure used in this study were approved by the ethics committee of Nara Medical University.

Fig. 8. Appearance of the cartilage conduction transducer attached to the patient's tragus (left ear)

3. Results and discussion

The thresholds obtained from the measurement of air conduction and bone conduction are shown in Figure 9. The mean hearing levels calculated by the three-frequency pure tone average were 58.3 and 6.7 dBHL for air conduction and bone conduction, respectively. Considering that this patient's hearing ability is impaired for air conduction but not bone conduction, *i.e.*, the air-bone gap is wide, he was diagnosed as conduction hearing loss.

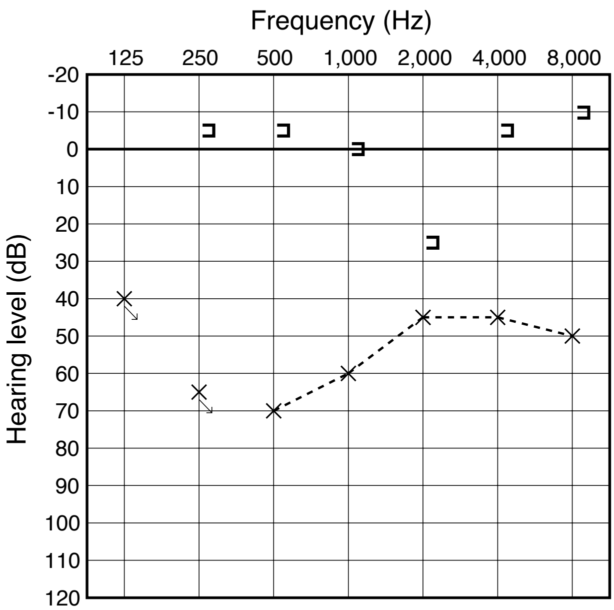

Fig. 9. The hearing thresholds for air and bone conduction on the audiogram (×: air conduction, : bone conduction)

The threshold for cartilage conduction is shown in Figure 10. The calculated mean hearing level was 3.3 dBHL, which is superior to that of air conduction. When compared with bone conduction, the hearing level of cartilage conduction was comparable to that of bone conduction. Hence, the cartilage conduction root can be used in order to get the good hearing for the patient.

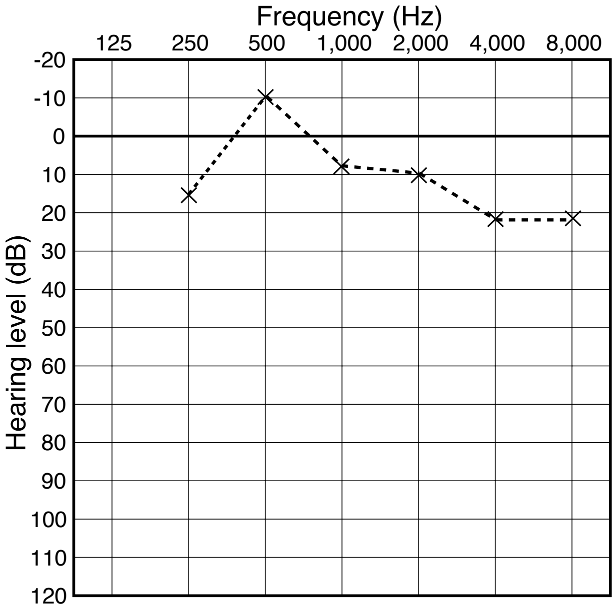

Fig. 10. The hearing threshold for cartilage conduction on the audiogram

Since we confirmed the efficiency of the cartilage conduction transducer in transmitting auditory stimuli, we applied this transducer to a hearing aid (Figure 11). This is the first hearing aid to use sound transmission via cartilage, and is referred to as a 'cartilage conduction hearing aid'.

Fig. 11. Cartilage conduction hearing aid developed in this study. It consists of a cartilage transducer (right) and microphone/amplifier complex (white box on left). The red circle is convenient to fix the cartilage conduction transducer to the tragus

The transducer and the microphone/amplifier complex weigh 6 g and 69 g respectively. According to the description from patients using the cartilage conduction hearing aid, their subjective hearings were comparable to those of bone conduction hearing aids. Because neither strong pressure nor surgery is necessary for the cartilage conduction hearing aid, It is expected to be useful for patients who cannot use regular air conduction hearing aids.

Frequency responses of the cartilage conduction hearing aid were measured. The sensitivity of the microphone were calibrated as -52dB, 0dB: 1V/0.1 Pa. The frequency response curves of the input voltage level to the cartilage transducer of the hearing aid at the maximum volume position are shown in Figure 12. Curves are plotted for the input sound pressure levels at 40, 50, 60, 70 and 80 dB. As input voltage level (decibels), the ratio of the RMS value of the voltage (reference value of 1V) that is transformed into common logarithm and then increased twenty-fold was used. The frequency response curves of the output force level from the cartilage transducer measured by the mechanical coupler (IEC 60373) for static force 3N is shown in Figure 13. As force level (in decibels),the ratio of the RMS value of the force transmitting vibration (reference value of 1 μN) that is transformed into common logarithm and then increased twenty-fold was used. The hearing levels calculated from the values of Figure 13 is shown in Figure 14. Those hearing levels were calculated based on the Reference Equivalent Threshold Force Level defined by ISO 389-3.

4. Conclusions

Final purpose of the present study was to develop a cartilage conduction hearing aid suitable for practical use. For this aim, we examined the hearing ability of a patient with atresia of the external auditory meatus via three conduction pathways (air, bone, and cartilage). Our results showed that the patient's hearing ability was dramatically increased with cartilage conduction compared with air conduction to a level comparable with bone conduction. Since we had confirmed the efficacy of the cartilage conduction transducer in sound transmission, we made a prototype of a cartilage conduction hearing aid. Although the experiments on the cartilage conduction hearing aid are in progress, subjective reports from patients suggest that a cartilage hearing aid would be useful and practical.

Although the cartilage conduction transducer improved the hearing of this patient remarkably, the transmission pathway of auditory stimuli in cartilage conduction is still unknown. It is also not yet determined whether sound localization will be possible if cartilage hearing aids were worn on both ears. Research about the cartilage conduction hearing aid is in a germinal stage, these questions, and others regarding the practical use of cartilage conduction hearing aids, should be examined in future studies.

Acknowledgements

This research was supported by a Health and Labour Science Research Grants for the Sensory and Communicative Disorders from the Ministry of Health, Labour and Welfare, Japan.

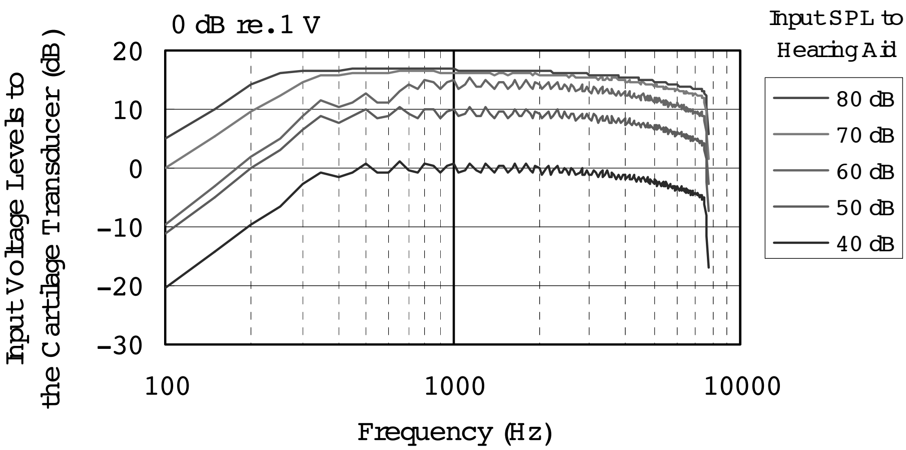

Fig. 12. Frequency responses curves of the cartilage conduction transducer

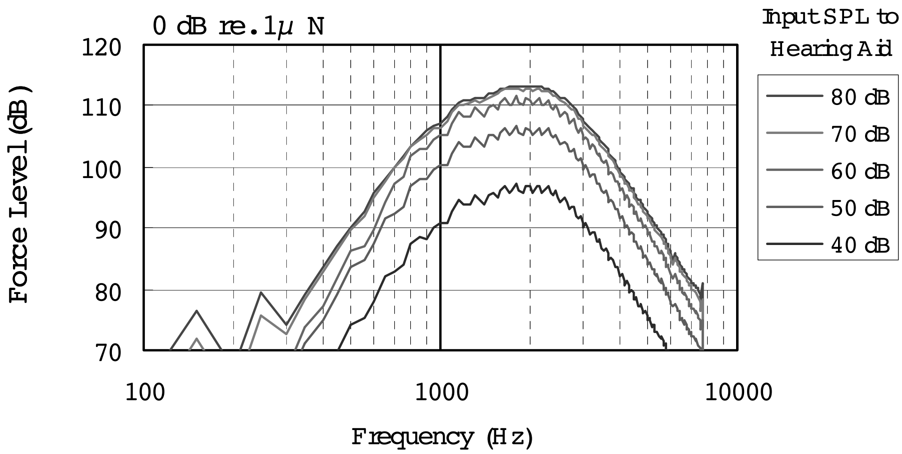

Fig. 13. Frequency response curves of the output force level from the cartilage conduction transducer

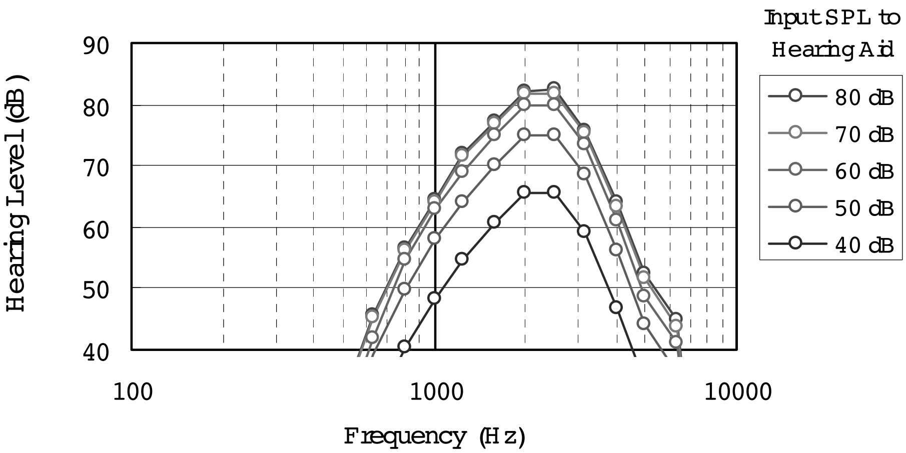

Fig. 14. Calibrated hearing levels of the cartilage conduction hearing aid

References

[1] P.L. Rice, Health Psychology, An International Thompson Publishing, Washington DC, 1988.

[2] R. Stewart, A. Wingfield, Hearing loss and cognitive effort in older adults' report accuracy for verbal materials, Journal of American Academy of Audiology 88 (2009) 147-154.

[3] P.A. Tun, S. McCoy, A. Wingfield, Aging, hearing acuity and the attentional costs of effortful listening, Psychology of Aging 24 (2009) 761-766.

[4] J. Bondy, S. Becker, I. Bruce, L. Trainor, S. Haykin, A novel signal-processing strategy for hearing aid design: Neurocompensation, Signal Processing 84 (2004) 1239-1253.

[5] C.V. Palmer, A. Ortmann, Hearing loss and Hearing aids, Neurologic Clinics 23 (2005) 901-918.

[6] J.E. Preminger, R, Carpenter, C.H. Ziegler, A clinical perspective on cochlear dead regions: Intelligibility of speech and subjective hearing aid benefit, Journal of American Academy of Audiology 16 (2005) 631-632.

[7] A.F.M. Snik, E.A.M. Mylanus, C.W.R.J. Cremers, Aided free-field thresholds in children with conductive hearing loss fitted with air- or bone-conduction hearing aids, International Journal of Pediatric Otorhinolaryngology 30 (1994) 133-142.

[8] H. Sohmer, S. Freeman, Further evidence for a fluid pathway during bone conduction auditory stimulation, Hearing Research 193 (2004) 105-110.

[9] H.W. Yuen, D. Bodmer, K. Smilsky, J.M. Nedzelski, J.M. Chen, Management of single-sided deafness with the bone-anchored hearing aid, Otolaryngology, Head and Neck Surgery 141 (2009) 16-23.

[10] M.A. Shirazi, S.J. Marzo, J.P. Leonetti, Perioperative complications with the bone-anchored hearing aid, Otolaryngology, Head and Neck Surgery 134 (2006) 236-239.

[11] A. Banerjee, E.V. Bordatchev, S.K. Choudhury, On-line monitoring of surface roughness in turning operations with opto-electrical transducer, International Journal of Manufacturing Research 4 (2009) 57-73.

[12] L. Bicci, A. Scorzoni, P. Placidi, L. Marrocchi, M. Cicioni, L. Roselli, S. Zampolli, L. Masini, I. Elmi, G.C. Carinali, A smart gas sensor for environmental monitoring, compliant with the IEEE 1451 standard and featuring a simplified transducer interface, International Journal of Intelligent Systems Technologies and Applications 3 (2007) 63-79.

[13] R. Grimberg, A. Savin, R. Steigmann, Eddy current inner transducer with rotating magnetic field: application to PHWRs pressure tubes, International Journal of Materials and Product Technology 26 (2006) 177-186.

[14] D. Liang, H.F. Xhang, L. Ying, Compressed-sesnsing photoacoustic imaging based on random optical illumination, International Journal of Functional Informatics and Personalised Medicine 2 (2009) 394-406.

[15] X.J. Zhu, Y.X. Gao, H.J. Xu, A new ultrasonic vibration machine for honing, International Journal of Computer Applications in Technology 29 (2007) 216-29.