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Acoustic input impedance of infants with normal and pathological middle ear

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Abstract

Newborns and infants often suffer from pathological conditions of the middle ear. In many cases, those conditions comprise liquid in the middle ear, e.g. middle ear effusion, or amniotic fluid during the very first days of life. In order to check the middle ear status in a fast and simple manner, the measurement of the infant's ear acoustic input impedance could be a useful method.

In an ongoing study, the acoustic input impedance of infants' ears (aged from 2 weeks up to 5 months) was measured in the frequency range from 100 Hz to 10 kHz at ambient pressure. In addition, the middle ear status was assessed by ENT-specialists, yielding an expert classification of "normal" and "pathological" middle ears. The results, on the one hand, show a great variability at low and very high frequencies, reflecting the susceptibility of the measurements to movements and noise of the subjects. On the other hand, there is a frequency range in which a clear discrimination between normal and pathological middle ears seems to be possible. This discrimination appears to profit from the consideration of both the magnitude and phase information of the measured acoustic impedance, indicating that power-based methods may miss important information.

Keywords: middle-ear, newborn, impedance, immittance

1 INTRODUCTION

The assessment of hearing ability in newborns and infants is a challenging task. Universal newborn hearing screening (UNHS) programs have the goal to identify infants with a permanent hearing loss in order to allow an early intervention.

Temporary pathological conditions of the middle ear are probably the most common cause of fails in UNHS-tests, but the results of these tests don't provide any information about the location of the problem.

In older children and adults tympanometry is the method of choice for detecting middle ear pathologies affecting the conductive path. In newborns and young infants tympanometry at 1 kHz is often used, but it seems that there is no commonly accepted method for interpreting the results.

Over the last years, other immittance-based measurements have been and still are investigated for their suitability to detect conductive problems in newborns and young infants, see e.g. [1, 2, 3, 4, 5]. In contrast to the classical single frequency tympanometry, these modern methods make use of a broader frequency range. They can be grouped by two factors: 1) whether the static pressure in the ear canal is changed or not, and 2) by the resulting quantity to be analyzed. Some methods report complex-valued quantities, such as the acoustic impedance or its reciprocal the acoustic admittance. The others are power based methods reporting real-valued quantities such as power-reflectance or power-absorbance. So far only power based methods are used in clinics.

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The present paper presents first results of an ongoing study, in which the acoustic input impedance of the ear of young infants with normal or pathological middle ear was measured. The status of the middle ear was assessed by ENT-specialists based on visual inspection of the ear together with results of a screening test and a 1 kHz tympanometry test.

2 METHODS

2.1 Subjects

The infants age had to be less than 5 month to be included into the study. Furthermore infants were excluded in case of known trisomy 21, any pharyngeal arch syndromes with a somatically different ear canal structure, or a dysplasia of the outer or middle ear. The study was carried out at *Medizinisches Versorgungszentrum Oldenburg* (MEVO), which is an outpatient ENT department specialized to pediatric audiology. Parents, coming to a regular consultation-hour into MEVO because their infants failed at least one time the NHS, where asked for parental consent to participate in the study.

The study-design was approved by the medical ethics committee of the University of Oldenburg.

2.2 Impedance measurement technique

The acoustic input impedance of the ear was measured with a custom-made measurement probe. This impedance probe contains a miniature electret microphone (Knowles Electronic type FG-23652-P16) and a balanced armature driver (Knowles Electronic type TWFK-30017). Both, microphone and driver were connected to separate ducts in a cylinder. The cylinder can be equipped with standard silicon ear tips. A third duct in the cylinder with an inner diameter of 0.6 mm provides pressure equalization between the ear canal and ambient pressure.

Impedance was measured using a calibrated source method. The method is based on [6] with additional consideration of discontinuity and end corrections. It is described in detail in [7]. The resulting calibration parameters could than be used to compute the acoustic impedance from the transfer function between microphone and receiver signal measured in the ear canal. Random pink noise signals were used for the measurements at an A-weighted sound pressure level of 63 dB SPL measured in a high-frequency coupler with a volume of 0.4 cm^3 (GRAS Sound & Vibration A/S type RA0252). The transfer functions were estimated using classical FFT-based estimation techniques [8].

Signal generation, recording and transfer function estimation were realized in MATLAB. A multi channel sound card (RME type Fireface UC) was used for conversion between digital and analog signals.

2.3 Protocol of ENT-specialists

The regular examination comprised 1 kHz tympanometry, automated auditory brainstem response (AABR)-screening and/or otoacoustic emission (OAE)-screening, and visual inspection by microscopy.

For the tympanometry a Maico Race Car Tympanometer was used. With a stimulus frequency of 1 kHz at a level of 85 dB SPL, the static pressure was varied from 200 daPa to -300 daPa at an adaptive rate.

Two different devices were used for AABR screening tests depending on which one was available. One of the devices was a Maico MB 11 Beraphone with CE-chirp stimuli at a rate of 93/s and a level of 35 dB nHL. The other device was a GSI Novus which also utilizes CE-chirps at a level of 35 dB nHL. The stimulus rate of the latter device depends on the ear side, the probe for the left ear produces a rate of 88/s, while the right ear probe produces a rate of 92.5/s. In both devices an automated analysis reported either pass or fail.

OAE-screening was conducted using a GSI Corti. Transient evoked otoacoustic emissions were determined at six frequencies between 1.5 kHz and 4 kHz, the intensity of click stimuli was 80 dB SPL peak equivalent. A pass required a SNR of 4 dB at 3 out of 6 frequencies.

The visual inspection comprised examination of the outer ear, the ear canal and the eardrum. Findings of liquid in the middle ear or blockage of the ear canal with cerumen were noted for the study. Finally, the status of the middle ear was assessed, considering all results of the regular examination, to be *normal*, *pathological*, or to be *unclear* if a decision was not possible at that time.

2.4 General procedure

Infants first underwent the screening test (AABR and/or TEOAE), followed by the 1 kHz tympanometry. After that, parents were asked for parental consent to participate with their child in the study. If a consent was given, the acoustic impedance was measured. Usually all tests and measurements were conducted in both ears, while the infant was awake. Finally, the visual inspection was done.

3 RESULTS

30 ears of 24 infants were assessed to have a normal middle ear and 13 ears were assessed to have a pathological middle ear. Figure 1 shows the numbers of ears for the normal and the pathological ears, respectively, grouped by age. As can be seen, in the group of normal middle ears the age of most subjects (80%) was less than 2 month. In the pathological group, only 37% were younger than 2 months and 40% were between 2 and 3 months.

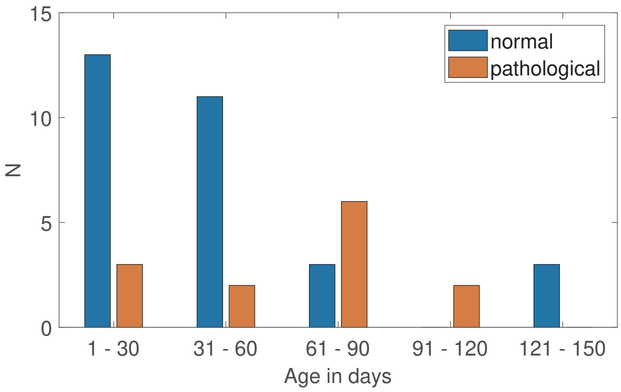

Figure 1. Numbers of normal and pathological ears, grouped by age.

It turned out that an assessment as "pathological" was always linked to middle ear effusion. While in one of the 13 middle ears the amount of secretion found was only small, in the other ears it was quite substantial.

Figure 2 shows the measured acoustic impedance of the normal ears on the left side and of the pathological ears on the right side. For the normal middle ears, a strong characteristic course of the acoustic impedance could be seen between about 1 kHz and 5 kHz, in both magnitude and phase. Below and above that frequency range, the variability increases. Furthermore, some artifacts (notches in impedance level and strong variations in phase) can be seen up to about 1.5 kHz, which are caused by a poor SNR in the measurement due to noise.

The acoustic impedance measured in the pathological middle ears shows substantially different characteristics. Except for two measurements, the level of the impedance has a minimum around 4 kHz with a steep gradient in phase. The first of the two exceptions, which is depicted as straight red line, has a decreasing impedance level and a phase near -90°. The ENT-specialist reported a very narrow ear canal with a protrusion at the posterior ear canal wall. The second exception is depicted by the green straight line. Both, level and phase of the acoustic impedance are quite similar to that of the normal ears with the level ranging in the upper limit of the impedances measured in normal ears. For that ear the ENT-specialist reported only a small amount of secretion in the middle ear.

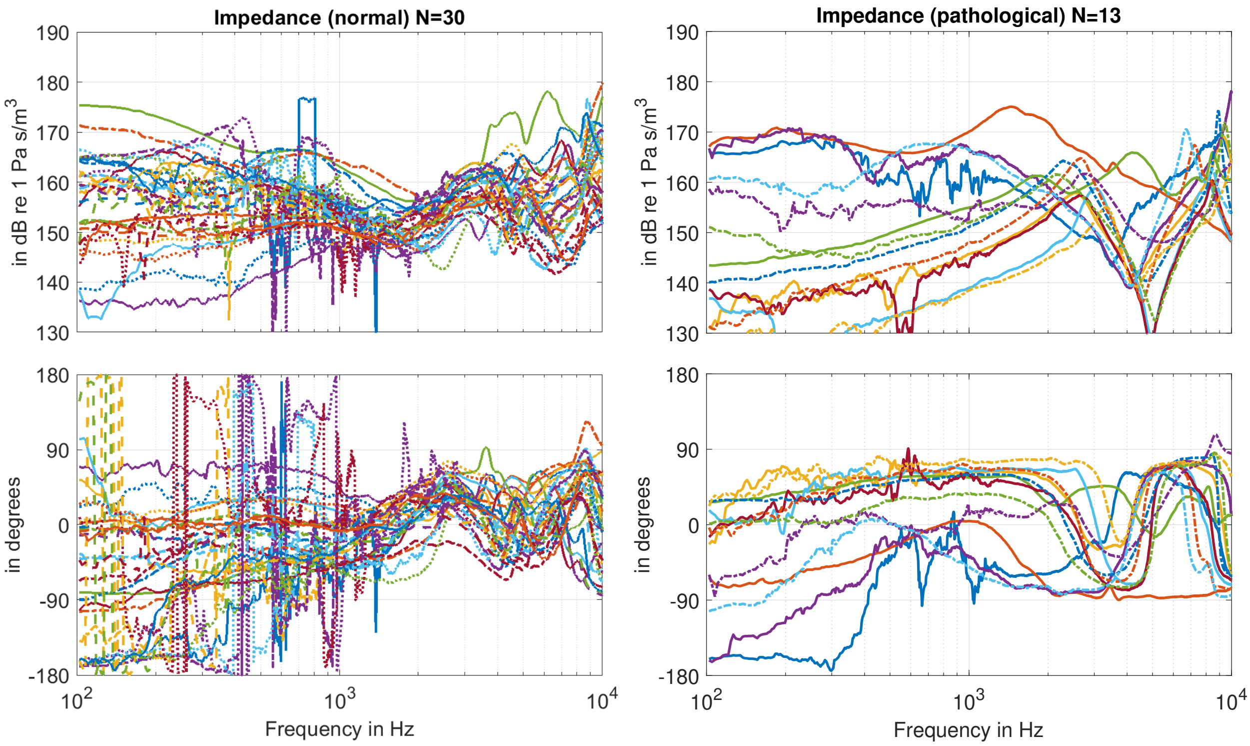

Figure 2. Acoustic input impedance of the ear measured on 30 infant ears with normal middle ear (left) and on 13 infant ears with pathological middle ear (right).

4 DISCUSSION

4.1 Problematic frequency ranges

At low frequencies, results are widely spread in both magnitude and phase. One of the reason for that, as already mentioned in the previous section, is a poor SNR. Additionally to the noise produced by the infants during the measurement, the design of the probe is not optimal in terms of SNR. The third duct in the cylindrical probe tip, providing equalization of static air pressure between ear canal and environment, causes a low signal level at low frequencies. On the other hand, the pressure equalizing duct avoids overpressure that might be caused when inserting the probe into the ear. This was intended and supposed to help avoid erroneous influences on the acoustic impedance of the ear and increase the infant's acceptance of the measurement.

Another reason for the widely deviating results at low frequencies is that the sealing of the ear canal by the probe differs between measurements. A highly sealed fitting of the probe results in a compliance like impedance at low frequencies, i.e. an impedance level decreasing with increasing frequency and a negative phase, which can be seen in some measurements. On the other hand, a loose fitting probe results in an acoustic leakage with a mass like impedance at low frequencies, i.e. an impedance level increasing with frequency and a positive phase. It should be noted that the pressure equalizing duct of the probe doesn't effect the measured impedance in terms of the sealing: As this duct is also present in the impedance calibration measurements, it is part of the source model.

Both problems, the poor SNR and the variations in sealing, result from challenges arising with measurements on very young infants. Of course, different actions could be taken to reduce these problems. However, it is assumed that the low frequency range isn't of much importance to detect pathological middle ear functions because at that age compliant ear canal walls affect the measured acoustic impedance, see [9].

At high frequencies (> 5 kHz), results are different between normal and pathological middle ears. Most impedance measurements on pathological middle ears show a peak in the impedance magnitude with a phase changing from positive to negative values at high frequencies, which is only shifted in frequency between different ears. Acoustic impedance measured on normal middle ears don't show a clear and simple characteristic course in that frequency range. It may be assumed that these variations are caused by individual differences in the middle ear and the residual ear canal. A further investigation of these effects will be part of future work.

4.2 Meaningful frequency range

The measured acoustic impedance in the frequency range from 1 kHz to 5 kHz showed clear characteristics, which can be assigned either to the middle ears assessed to be normal or to the ears assessed to be pathological due to middle ear effusion. These characteristics for the normal middle ears are a broad minimum in impedance level with gradually increasing phase at about 1.8 kHz, followed by a broad maximum of impedance level with gradually decreasing phase around 3.5 kHz. Characteristics of the pathological middle ears are a sharp minimum in impedance level with a steeply increasing phase around 4 kHz.

In [9] the acoustic input impedance of the ear on infants of different age groups was measured. These authors reported mean values for infants aged 1, 3, 6, 12, and 24 months old. The mean acoustic impedance reported for the 1, and 3 month groups showed the same characteristics, that were also found for the normal group in the present study.

In [3] wideband reflectance (WBR) was measured at infants aged from 3.1 to 25.6 weeks. WBR is a measure based an the acoustic impedance, it is also known as power-reflectance. The authors compared WBR measured on normal hearing (NH) infants with WBR measured on infant ears having a conductive hearing loss (CHL). Assessment of NH and CHL was achieved by determining the air-bone gap from air conduction thresholds and bone conduction thresholds measured with auditory brainstem response. WBR was determined at 15 1/3 octave bands in the frequency range from 211 Hz to 6 kHz. They found the frequency range around 1.6 kHz to be suitable to distinguish between NH and CHL, which is in agreement with the characteristics found in the present study. In contrast to the above presented results, the WBR-values didn't allow a distinction between NH and CHL around 4 kHz.

5 CONCLUDING REMARKS

In the present contribution, measurements of the acoustic input impedance of the ear, measured at ambient pressure in young infants up to 5 months old, were presented. The infants were awake during the measurement. The middle ear status of the ears were assessed either to be normal or to be pathological, with the latter always being associated with middle ear effusion.

Different characteristics between normal and pathological middle ears could be found in both, impedance magnitude and phase. The results strongly indicate that the acoustic impedance measured at ambient pressure is suitable to detect middle ear effusion in young infants.

The impedance measured in the present study on normal assessed middle ears is in good agreement with mean values from literature.

At high frequencies (> 5 kHz), the acoustic impedance measured on ears where middle ears were assessed to be normal showed considerable inter-individual variations. The investigation of these variations will be part of future work.

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