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Effects of ear canal static pressure on the dynamic behaviour of outer and middle ear in newborns☆

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ABSTRACT

Objective: The present study investigated the effect of ear canal pressure on the dynamic behaviour of the outer and middle ear in newborns with and without a conductive condition using the sweep frequency impedance (SFI) technology.

Methods: A test battery consisting of automated auditory brainstem response (AABR), transient evoked otoacoustic emission (TEOAE) and 1000-Hz tympanometry (HFT) was performed on 122 ears of 86 healthy newborns and 10 ears of 10 newborns with a conductive condition (failed TEOAE and HFT). The dynamic behaviour of the outer and middle ear, when the pressure applied to the ear canal was varied from 200 to −200 daPa, was evaluated in terms of the sound pressure level (SPL) in the ear canal, resonance frequency (RF) and displacement (ΔSPL).

Results: Application of either a positive or negative static pressure to the ear canal of healthy newborns increased the resonance frequency of the outer (RF1) and middle ear (RF2), but decreased the displacements of the outer (ΔSPL1) and middle ear (ΔSPL2). Positive static pressures resulted in lower SPL while negative static pressures resulted in higher SPL than that at ambient pressure (0 daPa). At −200 daPa, more than 90% of ears showed signs of collapsed ear canal. The dynamic behaviour under various positive and negative static pressures for newborn ears with a conductive condition indicated similar pattern of SPL, RF1 and ΔSPL1 responses for the outer ear as per healthy ears, but abnormal responses for the middle ear.

Conclusions: While both positive and negative pressures applied to the ear canal have the same effect of stiffening the outer and middle ear, negative pressure of up to −200 daPa resulted in more than 90% of ears with a collapsed ear canal. The results of the present study do not only offer useful clinical information for differentiating healthy ears from ears with a conductive condition, but also provide information on the maturation aspects of the outer and middle ear in newborns.

1. Introduction

Technological advances have enabled the measurement of acoustical characteristics of the outer and middle ear using multifrequency tympanometry (MFT) [1]. MFT refers to the measurement of middle ear characteristics using tones of more than one frequency. The MFT procedure may either use a sweep frequency technique at multiple applied air pressures to the ear canal or a sweep pressure technique using tone of multiple discreet frequencies [2,3]. The MFT procedure may also utilise a wideband technique using click stimuli at ambient or multiple applied air pressure to the ear canal [4].

At present, new multi-frequency techniques that measure acoustic-mechanical properties over a wide frequency range have been developed to assess the outer and middle ear function. Two such techniques are sweep frequency impedance (SFI) [1,5] and wideband acoustic immittance (WAI) [5–8]. The SFI metre, developed by Wada et al. [9], measures the sound pressure in the ear canal while a sweeping tone is presented under various

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static pressure levels in the ear canal. From the SFI measures, the dynamic behaviour of the outer and middle ear can be described in terms of the sound pressure level (SPL) across frequencies at various static pressure applied to the ear canal. From the SPL results, the resonance frequency (RF) and mobility of the outer and middle ear system (ΔSPL) can be measured [9]. While the SFI is similar in principle to MFT, it does not measure the admittance of the outer and middle ear. Instead, it measures the SPL in the ear canal in dB SPL across the frequencies from 100 to 2200 Hz. The SFI has advantages over the traditional MFT. It is faster than the MFT and it also measures the RF accurately regardless of the direction and rate of change of ear canal pressure. The SFI test has also been reported to be better than the 226-Hz tympanometry in the differential diagnosis of middle ear dysfunction in adults [1,5,9–12].

The dynamic behaviour of the outer and middle ear system, as analysed using the SFI metre, of a normally hearing adult is different from that of a healthy newborn (Fig. 1). The SFI results at ambient pressure (0 daPa) for the adult reveal one inflexion [Fig. 1(a)], while the results for the newborn reveal two inflexions [Fig. 1(b)]. The differences in dynamic behaviour may be attributed to differences in the anatomy and physiology of the outer/middle ear between the adult and the newborn.

From an anatomical and physiological perspective, the outer and middle ear system of newborns is not mature at birth [13]. There is a thin layer of elastic cartilage surrounding the entire external auditory canal [14] which makes the ear canal relatively compliant, flaccid and prolapsed [15–17]; newborns have a short ear canal with diameter increasing to 4.4 mm by the age of one month [18] and a short ear canal floor length of 17–22.5 mm and roof length of 11–22.5 mm by age of two month [14]. Orientation of the newborn eardrum is more horizontal relative to the ear canal axis [18–20]. The middle ear and mastoid cavities are small (452 mm^3) compared to adult tympanic cavity (640 mm^3) [14,16,21]. Newborns also have loose ossicular joints [14,22] which become more stiff with age.

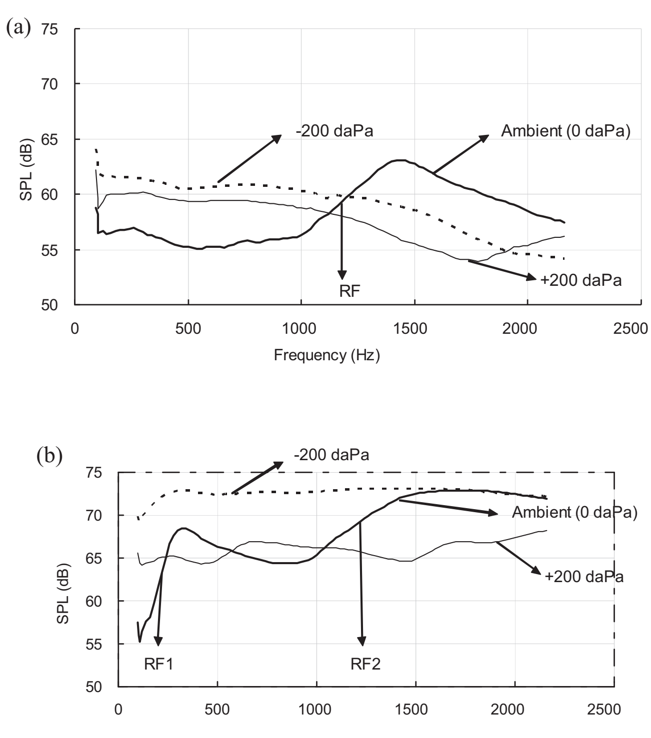

Fig. 1. SFI results obtained (a) from a normal hearing adult who passed 226 Hz tymp. The SPL curve at ambient pressure shows single variation at around 1220 Hz; (b) from a normal hearing newborn who passed HFT and TEOAE. The SPL curve at ambient pressure shows two variations in sound pressure, one (RF1) at around 260 Hz and the second (RF2) at around 1220 Hz. *Note*: RF = resonance frequency.

The anatomical and physiological properties of healthy newborns are altered when an external air pressure is applied to the ear canal. On pressurisation, the cartilaginous ear canal diameter increases by an average of 18.3% under positive pressure or decreases by an average of 28.2% of its original value under negative ear canal pressure [23]. Furthermore, ear canal volume changes from 27 to 75% over a range of ±300 daPa in newborns [22]. In view of these characteristics, the dynamic behaviour of the outer and middle ear of newborns will undoubtedly change in response to pressurisation of the ear canal [15,16,24]. These changes in dynamic behaviour of the outer and middle ear can easily be described using the SFI technique.

While the SFI has been successfully used with children and adults, its application to newborns is relatively new. To date, only two studies have investigated the dynamic behaviour of the outer and middle ear of newborns [25,26]. In a pilot study, Murakoshi et al. [26] analysed SFI data obtained from 9 neonates under ambient ear canal pressure (0 daPa) condition and found two resonances corresponding to the two inflexions of the sound pressure level (SPL) curve (Fig. 1b). By comparing their results with that obtained from a gel model which mimicked a newborn ear canal, they showed that the first resonance which occurred at 260 Hz ± 30 Hz, was related to the resonance of the ear canal wall. The second resonance, which occurred at 1130 ± 120 Hz was related to the resonance of the middle ear. Aithal et al. [25] studied the dynamic behaviour of the outer and middle ear of healthy newborns under ambient pressure conditions using a larger sample (N = 100) and reported normative data for the resonance frequencies and ΔSPL (mobility of the system). Their findings were consistent with the results of Murakoshi et al. [26]. Furthermore, they affirmed the feasibility of assessing the function of the outer and middle ear in newborns using the SFI technique.

While the dynamic behaviour of the outer and middle ear in newborns under ambient pressure condition was described in detail by Murakoshi et al. [26] and Aithal et al. [25], the dynamic behaviour under pressurised conditions has not been systematically investigated. Investigation of the effect of ear canal pressure on the dynamic behaviour in newborns is important since the ear canal and tympanic membrane of newborns are compliant and flaccid. The present study aimed to investigate the dynamic behaviour of outer and middle ear by inducing positive and negative ear canal pressures in newborn ears. In particular, the study was conducted to address the following questions: (i) is the dynamic behaviour under pressurised conditions significantly different to that under ambient pressure condition? (ii) Does the dynamic behaviour differ significantly between positive and negative ear canal pressures? (iii) Is the dynamic behaviour under pressurised conditions of a healthy newborn different from that of an ear with a conductive condition?

2. Materials and methods

2.1. Participants

This study was approved by the Human Research Ethical Committee of Townsville Hospital and Health Service, and the University of Queensland Behavioural and Social Science Ethical Review Committee. Parents provided written consent for newborns to be included in the study. The present study included 122 ears from 86 healthy newborns (45 males and 41 females) who passed in a test battery that included automated auditory brainstem response (AABR), transient evoked otoacoustic emission (TEOAE) and high frequency tympanometry (HFT) with a 1000-Hz