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Air-bone gap estimated with multiple auditory steady-state response in young children with otitis media with effusion

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ABSTRACT

Objective: Multiple auditory steady-state responses (ASSRs) to air- and bone-conduction stimuli were recorded in young children with otitis media with effusion (OME). After treatment for OME, differences between pre-treatment bone-conduction ASSR levels and post-treatment conditioned orientation reflex (COR) or air-conduction ASSR levels were examined, and compared with ASSR-estimated air-bone gap (ABG) before treatment.

Methods: Navigator Pro with Master was used to assess the threshold of air- and bone-conduction ASSR in both ears at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. For bone-conduction ASSR, RadioEar B-71 bone-vibrator placed on the mastoid was used with white-noise masking on the contralateral ear.

Results: After ventilation tube placement, the thresholds of COR got closer to those of pre-treatment bone-conduction ASSR in young children with OME. Moreover, post-treatment air-conduction ASSR thresholds also got closer to those of pre-treatment bone-conduction ASSR. The differences between pre-treatment bone-conduction ASSR thresholds and post-treatment COR or air-conduction ASSR thresholds became much smaller than ASSR-estimated ABG before treatment.

Conclusion: These findings suggest that bone-conduction ASSR can assess the normal or near normal cochlear sensitivity in young children with conductive hearing loss. It is also suggested that ASSR-estimated ABG can be used clinically to predict their accurate ABG.

1. Introduction

The auditory evoked potential is required to estimate hearing thresholds for individuals who cannot respond reliably to behavior testing such as infants, young children and emotionally disturbed or cognitively impaired patients. The auditory brainstem response (ABR) is currently used clinically for threshold assessment in infants and young children. However, the ability of ABR to click tone to detect an auditory response is limited at high frequencies. Although ABR to tone-pips of 500 Hz or 1000 Hz is used to overcome the limitation, its error of prediction was reported especially in patients with steeply sloping audiograms [1].

The auditory steady-state responses (ASSR) evoked by auditory stimuli that are sinusoidally modulated in amplitude at rate between 80 and 110 Hz are used to evaluate auditory thresholds objectively [2]. ASSR can be simultaneously recorded for multiple carrier frequencies in both ears. ASSR with multiple simultaneous stimulation technique (multiple ASSR) to air-conduction stimuli have been found to provide accurate prediction of hearing thresholds at 500, 1000, 2000 and 4000 Hz. The ASSR thresholds at 1000 Hz, 2000 Hz and 4000 Hz are elevated by less than 10 dB, compared to behavioral thresholds, but those at 500 Hz are elevated by a bit more than 10 dB than those at higher frequencies.

In order to distinguish between sensorineural and conductive hearing loss, the ASSR thresholds to bone-conduction stimuli must be evaluated, as it is routinely done in behavioral audiometry. It was reported that multiple ASSR are recorded in response to the stimuli directly through a bone conduction transducer positioned either on the forehead [3,4] or on one of the mastoids [5] in adults. Moreover, air-bone gap (ABG) estimated with multiple ASSR to air- and bone-conduction stimuli was reported to be strongly correlated with that measured using pure-tone audiometry in adults with simulated conductive hearing loss [6].

In the present study, we recorded multiple ASSR to air- and bone-conduction stimuli and assessed ASSR-based ABG in young children with otitis media with effusion (OME). To prove a reasonably accurate prediction of ABG with ASSR in young children with conductive hearing loss, differences between pre-treatment

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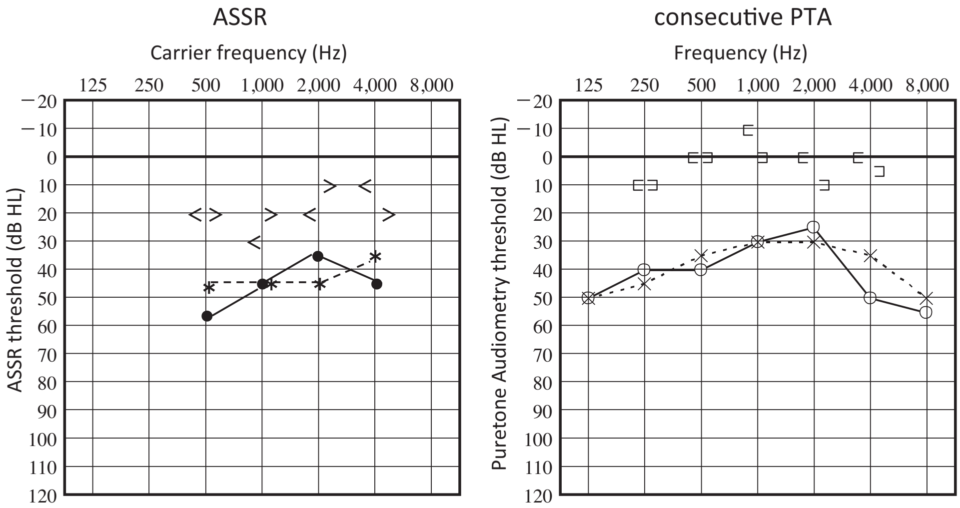


Fig. 1. Air- and bone-conduction thresholds with multiple ASSR and air- and bone-conduction ones with the consecutive pure-tone audiometry in case 3 of a 6-year and 11-month child with ossicular malformation found on CT. ●: air-conduction ASSR of right ear, *: air-conduction ASSR of left ear, <: bone-conduction ASSR of right ear, >: bone-conduction ASSR of the left ear.

bone-conduction ASSR levels and post-treatment COR or air-conduction ASSR levels were examined, and compared with ASSR-estimated ABG before treatment

2. Subjects and methods

2.1. Subjects

Nine children with conductive hearing loss were enrolled in the present study. In three children, the bone-conduction ASSR thresholds were assessed and then the bone-conduction levels on peep-show or pure-tone audiometry were assessed on the same day. The subgroup included a 3-year and 6-month infant with first and second brachial syndrome, a 5-year and 1-month child with malleus malformation and another child aged 6 years and 11 months with ossicular malformation found on CT. Also, four children had OME and their bone-conduction ASSR thresholds were assessed form the age of 4 months to 1 years and 3 months. After the treatment with ventilation tube placement or myringotomy, the air-conduction levels on conditioned orientation reflex (COR) audiometry were assessed from the age of 6 months to 2 years and 7 months. Finally, in two children with OME, the bone-conduction ASSR thresholds were assessed at the age of 2 months. After myringotomy, the air-conduction ASSR thresholds were assessed at the age of 3 months and 4 months. This study was approved by the Committee for Medical Ethics of Tokushima University Hospital.

2.2. Methods

Navigator Pro with Master (Multiple Auditory STEady-state Response) was used to assess the threshold of air-conduction ASSR in both ears at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz simultaneously [7]. Also the bone-conduction ASSR threshold in both ears at the same frequencies was also assessed alternatively with RadioEar B-71 bone-vibrator which was placed on the mastoid with elastic band [8]. White-noise masking of 50 dB HL was used on the contralateral ear. Bone-conducted stimuli were calibrated in air-equivalent dB SPL based on American National Standards Institute and International Standards Organization. Stimuli of air- and bone-conduction were amplitude-modulated tone. The carrier frequencies and modulation frequencies were as follows: 500 Hz/82 Hz, 1000 Hz/84 Hz, 2000 Hz/87 Hz and 4000 Hz/89 Hz to the left ear, and 500 Hz/91 Hz, 1000 Hz/94 Hz, 2000 Hz/96 Hz and 4000 Hz/99 Hz to the right ear [9]. Air-conduction stimuli of 80–0 dB HL and bone-conduction stimuli of 50–0 dB HL were used.

3. Results

Multiple ASSR to bone-conduction stimuli were recorded in three young children with conductive hearing loss: case 1 with first and second brachial syndrome, case 2 with malleus malformation and case 3 with ossicular malformation found on CT (Fig. 1). The ASSR thresholds to bone-conduction stimuli were 15.8 dB at 500 Hz, 21.7 dB at 1000 Hz, 13.3 dB at 2000 Hz and 10.8 dB at 4000 Hz above consecutive behavioral bone-conduction thresholds (cases 1 and 2 on peep-show audiometry and case 3 on pure-tone audiometry) (Table 1).

The bone-conduction ASSR thresholds were lower than those of air-conduction in the four young children with bilateral OME. ASSR-estimated ABG in the ear with better air-conduction levels was 20–40 dB (32.5 ± 9.6 dB) at 500 Hz, 10–30 dB (22.5 ± 9.6 dB) at 1000 Hz, 0–10 dB (7.5 ± 5.0 dB) at 2000 Hz and 0–20 dB ($n = 3$ and 50 dB, $n = 1$) (22.5 ± 20.6 dB) at 4000 Hz. Three were treated with bilateral ventilation tube placement and one with bilateral myringotomy, and the air-conduction thresholds of the better hearing ear were assessed with COR audiometry. Accordingly, the differences between pre-treatment bone-conduction ASSR thresholds and post-treatment COR thresholds were 2.5 dB at 500 Hz, 5.0 dB at 1000 Hz, −1.9 dB at 2000 Hz and 2.5 dB at 4000 Hz, and were much smaller than ASSR-estimated ABG before treatment (Table 2). For example, in case 5 with bilateral OME, post-treatment of air-conduction level of

Table 1
Differences of bone-conduction levels between ASSR and consecutive behavior autiometry in children with susupected conductive hearing loss.

		500 Hz	1000 Hz	2000 Hz	4000 Hz
Case 1	R	20 dB	20 dB	20 dB	20 dB
	L	20 dB	20 dB	20 dB	10 dB
Case 2	R	10 dB	20 dB	10 dB	5 dB
	L	5 dB	15 dB	10 dB	5 dB
Case 3	R	20 dB	40 dB	20 dB	10 dB
	L	20 dB	20 dB	0 dB	15 dB
Average		15.8 ± 6.6 dB	21.7 ± 6.8 dB	13.3 ± 8.2 dB	10.8 ± 5.8 dB

Data represent bone-condution ASSR levels minus those of behavior audiometry. Average indicates mean ± S.D.

Table 2
Differences between pre-treatment bone-conduction ASSR levels and post-treatment COR levels in children with otitis media with effusion.

		500 Hz	1000 Hz	2000 Hz	4000 Hz
Case 4	pre-ASSR-based ABG	40 dB	30 dB	10 dB	0 dB
	R	10 dB	15 dB	0 dB	−5 dB
	L	0 dB	15 dB	0 dB	−5 dB
Case 5	pre-ASSR-based ABG	20 dB	20 dB	0 dB	20 dB
	R	−5 dB	−5 dB	−10 dB	−10 dB
	L	−5 dB	−5 dB	−10 dB	−10 dB
Case 6	pre-ASSR-based ABG	40 dB	30 dB	10 dB	20 dB
	R	15 dB	10 dB	10 dB	10 dB
	L	15 dB	10 dB	10 dB	10 dB
Case 7	pre-ASSR-based ABG	30 dB	10 dB	10 dB	50 dB
	R	−5 dB	0 dB	−10 dB	15 dB
	L	−5 dB	0 dB	−5 dB	15 dB
Average	pre-ASSR-based ABG	32.5 dB	22.5 dB	7.5 dB	22.5 dB
Average		2.5 ± 9.3 dB	5.0 ± 8.5 dB	−1.9 ± 8.4 dB	2.5 ± 11.0 dB

Data represent pre-treatment bone-conduction ASSR levels of each ear minus post-treatment COR levels. Average indicates mean ± S.D. ABG: air-bone gap Pre-ASSR-based ABG: pre-treatment air-conduction ASSR levels minus pre-treatment bone-conduction ASSR levels in the ear with better air-conduction ASSR levels.

Table 3
Differences between pre-treatment bone-conduction ASSR levels and post-treatment air-conduction ASSR levels in children with otitis media with effusion.

		500 Hz	1000 Hz	2000 Hz	4000 Hz
Case 8	pre-ASSR-based ABG	30 dB	30 dB	20 dB	10 dB
	R	10 dB	10 dB	5 dB	−5 dB
	L	20 dB	10 dB	5 dB	−15 dB
Case 9	pre-ASSR-based ABG	15 dB	5 dB	0 dB	10 dB
	L	5 dB	−5 dB	0 dB	0 dB
Average		11.7 ± 7.6 dB	5.0 ± 8.7 dB	3.3 ± 2.0 dB	−6.7 ± 7.6 dB

Data represent post-treatment air-conduction ASSR levels minus pre-treatment bone-conduction ASSR levels. Average indicates mean ± S.D. ABG: air-bone gap. Pre-ASSR-based ABG: pre-treatment air-conduction ASSR levels minus pre-treatment bone-conduction ASSR levels in ear with better air-conduction ASSR. Air-conduction ASSR was not recorded from the right ear in case 9.

the better hearing ear that assessed by COR got closer to the pre-treatment levels of bone-conduction ASSR (Fig. 2).

The bone-conduction ASSR thresholds were lower compared to those of air-conduction in two young children with bilateral OME. ASSR-estimated ABG in the ear with better air-conduction levels were 30 dB and 15 dB at 500 Hz, 30 dB and 5 dB at 1000 Hz, 20 dB and 0 dB at 2000 Hz and 10 dB and 10 dB at 4000 Hz, respectively. Air-conduction ASSR was not recorded with the right ear in case 9. They underwent bilateral myringotomy and the air-conduction ASSR thresholds were then assessed. The differences between pre-treatment bone-conduction ASSR thresholds and those of post-treatment air-conduction ASSR were 11.7 dB at 500 Hz, 5.0 dB at 1000 Hz, 3.3 dB at 2000 Hz and −6.7 dB at 4000 Hz, which were much smaller than ASSR-estimated ABG before treatment (Table 3). For example, in case 8 with bilateral OME, the post-treatment air-conduction ASSR level got closer to pre-treatment bone-conduction ASSR levels (Fig. 3).

4. Discussion

In the present study, multiple ASSR were recorded in response to bone-conduction stimuli at 30 dB and lower in

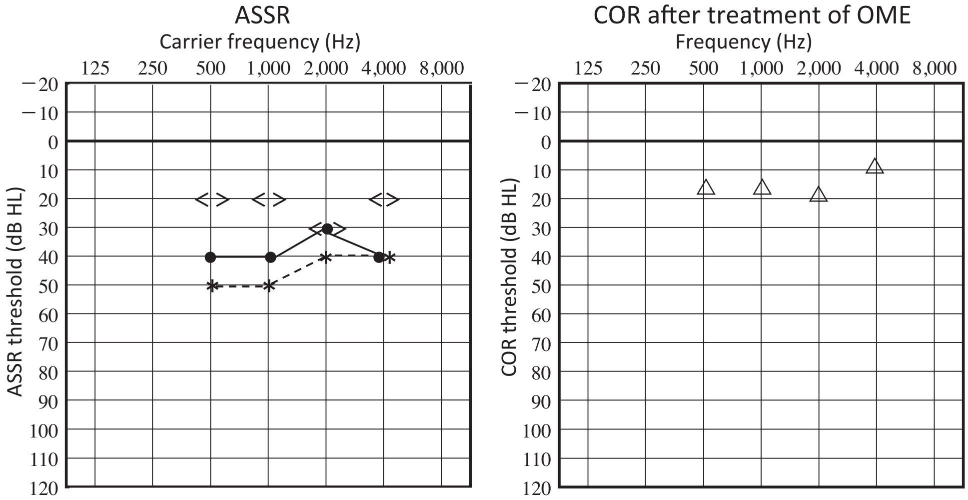
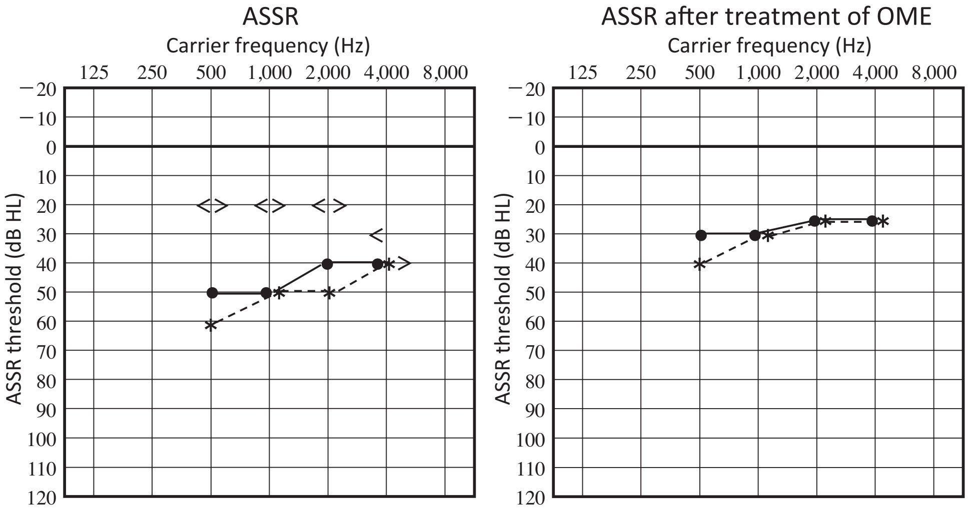


Fig. 2. Pre-treatment air- and bone-conduction thresholds with multiple ASSR in case 5 of bilateral OME at the age of 1 year, and after ventilation tube placement, post-treatment thresholds of air-conduction with COR at the age 2 years and a month. ●: air-conduction ASSR of right ear, *: air-conduction ASSR of left ear, <: bone-conduction ASSR of right ear, >: bone-conduction ASSR of the left ear.



ASSR

ASSR after treatment of OME

Fig. 3. Pre-treatment air- and bone-conduction thresholds with multiple ASSR in case 8 of bilateral OME at the age of 2 months, and after myringotomy, the post-treatment air-conduction thresholds with ASSR at the age of 4 months. ●: air-conduction ASSR of right ear, *: air-conduction ASSR of left ear, <: bone-conduction ASSR of right ear, >: bone-conduction ASSR of the left ear.

young children with conductive hearing loss. In adults, it was reported that reliable ASSR were obtained for bone-conduction stimuli up to 40 dB at 500 Hz and 50–60 dB at 1000 Hz, 2000 Hz and 4000 Hz [10]. In the present study, the thresholds of ASSR to bone-conduction stimuli in young children were slightly lower than those of bone-conduction assessed by consecutive behavioral audiometry, and the differences were larger at 500 Hz and 1000 Hz than at 2000 Hz and 4000 Hz (Table 1). Similar physiological-behavioral differences of bone-conduction thresholds were reported across frequency in adults [3,4]. Moreover, it was reported that in infant, the thresholds of bone-conduction ASSR worsen at low-frequency, but improve at high-frequency with maturation [11]. The age- and frequency-dependent variability of the thresholds of bone-conduction ASSR reduces after the neuromatuation of the brain stem and the increase of sound transmission across the skull of which sutures is fused in older infants [12].

In the present study, ABG was estimated with air- and bone-conduction ASSR in young children with OME: 32.5 dB at 500 Hz, 22.5 dB at 1000 Hz, 7.5 dB at 2000 Hz and 22.5 dB at 4000 Hz. After treatment for OME, the thresholds of COR got closer to those of pre-treatment bone-conduction ASSR (Table 2). Furthermore, ASSR-estimated ABG of less than 30 dB were observed in young children with OME, and post-treatment air-conduction ASSR thresholds got closer to those of pre-treatment bone-conduction ASSR (Table 3). These findings suggested that bone-conduction ASSR can assess the normal or near normal cochlear sensitivity in children with conductive hearing loss.

The differences between pre-treatment bone-conduction ASSR thresholds and those of post-treatment COR or air-conduction ASSR were much smaller than ASSR-estimated ABG before treatment (Tables 2 and 3). These findings suggest that the ASSR-estimated ABG can be used clinically to predict the accurate ABG in young children with conductive hearing loss.

Jeng et al. [6] estimated ABG with ASSR in normal adults with simulated conductive hearing loss and compared it with ABG measured by pure-tone audiometry. They showed that ASSR-estimated and behavioral ABGs were strongly correlated with each other. Furthermore, Swanepoel et al. [13] also reported that in children with conductive hearing loss, the threshold of bone-conduction ASSR corresponded very closely to those of children with normal hearing and their thresholds of air-conductive ASSR were elevated with a typical conductive hearing loss configuration.

In conclusion, despite the slight differences in bone-conduction thresholds between ASSR and behavioral audiometry, bone-conduction ASSR can assess the normal or near normal cochlear sensitivity in children with conductive hearing loss. Moreover, ASSR-estimated ABG can be used clinically to predict the accurate ABG in children with conductive hearing loss, because the differences between pre-treatment bone-conduction ASSR thresholds and post-treatment COR or air-conduction ASSR thresholds were much smaller compared to ASSR-estimated pre-treatment ABG. However, the clinical usefulness of ASSR-estimated ABG will be limited in children with mixed hearing loss, because artificial ASSR were reported to be induced by bone-conduction stimuli 50 dB and higher [10].

Conflict of interest

The authors state no conflicts of interest.

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References

[1] Hayes D, Jerger J. Auditory brainstem response (ABR) to tone-pips: results in normal and hearing-impaired subjects. Scand Audiol 1982;11:133–42.
[2] Picton TW, John MS, Dimitrijevic A, Purcell D. Human auditory steady-state responses. Int J Audiol 2003;42:177–219.
[3] Lins OG, Picton TW, Boucher BL, Durieux-Smith A, Champagne SC, Moran LM, et al. Frequency-specific audiometry using steady-state responses. Ear Hear 1996;17:81–96.
[4] Dimitrijevic A, John MS, Van Roon P, Purcell DW, Adamonis J, Ostroff J, et al. Estimating the audiogram using multiple auditory steady-state responses. J Am Acad Audiol 2002;13:205–24.
[5] Small SA, Stapells DR. Multiple auditory steady-state responses to bone-conduction stimuli in adults with normal hearing. J Am Acad Audiol 2005;16:172–83.
[6] Jeng FC, Brownt CJ, Johnson TA, Vander Werff KR. Estimating air-bone gaps using auditory steady-state responses. J Am Acad Audiol 2004;15:67–78.

[7] Lins OG, Picton TW. Auditory steady-state responses to multiple simultaneous stimuli. Electroencephalogr Clin Neurophysiol 1995;96:420–32.

[8] Small SA, Hatton JL, Stapells DR. Effects of bone oscillator coupling method, placement location, and occlusion on bone-conduction auditory steady-state responses in infants. Ear Hear 2007;28:83–98.

[9] Lins OG, Picton PE, Picton TW, Champagne SC, Durieux-Smith A. Auditory steady-state responses to tones amplitude-modulated at 80–110 Hz. J Acoust Soc Am 1995;97(5 Pt 1):3051–63.

[10] Small SA, Stapells DR. Artifactual responses when recording auditory steady-state responses. Ear Hear 2004;25:611–23.

[11] Small SA, Stapells DR. Multiple auditory steady-state response thresholds to bone-conduction stimuli in young infants with normal hearing. Ear Hear 2006;27:219–28.

[12] Small SA, Stapells DR. Normal ipsilateral/contralateral asymmetries in infant multiple auditory steady-state responses to air- and bone-conduction stimuli. Ear Hear 2008;29:185–98.

[13] Swanepoel de W, Ebrahim S, Friedland P, Swanepoel A, Pottas L. Auditory steady-state responses to bone conduction stimuli in children with hearing loss. Int J Pediatr Otorhinolaryngol 2008;72:1861–71.