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Measurements of vibration in the external auditory meatus caused by distantly presented bone conducted ultrasound

遠位呈示骨導超音波による外耳道振動の特性評価

Riki Ogino[1], Sho Otsuka[1, 2, 3], and Seiji Nakagawa[1, 2, 3†] ([1]Dept. of Medical Eng., Graduate School of Sci. & Eng., Chiba Univ.; [2]Ctr. for Frontier Medical Eng., Chiba Univ.; [3]Med-Tech Link Center, Chiba Univ. Hospital)

荻野利基[1]，大塚　翔[1, 2, 3]，中川誠司[1, 2, 3†]([1]千葉大学大学院融合理工学府医工学コース, [2]千葉大学フロンティア医工学センター，千葉大学医学部附属病院メドテック・リンクセンター)

1. Introduction

Ultrasound is usually described as inaudible sound having a freuency higher than 20,000 Hz. However, several studies have shown that high frequency sound up to at least 100,000 Hz can be heard clearly via bone conduction [1-3]; such ultrasound is referred to as bone-conducted ultrasound (BCU). Moreover, BCU hearing in humans has been found under various auditory pathological conditions, including sensorineural hearing loss and middle-ear disorders[3]. In particular, BCU is even perceived by profoundly sensorineural deaf persons, who cannot obtain sufficient audition even with the use of a conventional hearing aid. In addition, when BCU is amplitude-modulated by speech sounds, even profoundly deaf persons can perceive the amplitude modulation signal components as speech sounds, together with, but separately from, the carrier signal component of the BCU [4]. Thus we have developed a novel hearing aid using BCU [bone-conducted ultrasonic hearing aid (BCUHA)] for the profoundly deaf [5-7].

In the BCUHA, ultrasonic sinusoids with a frequency of about 30,000 Hz are amplitude-modulated by speech or environmental sounds detected by microphones and presented to the mastoid of the temporal bone by a vibrator. In hearing tests of profoundly deaf participants, more than 40% of profoundly deaf participants were able to perceive some sounds and 17% were able to recognize words[5]. This results demonstrated the potential of the BCUHA. However, BCUHA has room for improvement in various respects.

One of the largest disadvantages of bone-conduction devices is the discomfort in wearing the vibrator. The vibrator is usually pressed mastoid process of the temporal bone by a head band with a clamping pressure of 5 N. It is difficult to hold the vibrator steadily on a rounded surface of the mastoid process, and it is sometimes accompanied by pain and esthetic problems.

On the other hand, BCU can be heard not only via the mastoid process, but also via wider areas of the body, for example, the muscle of the neck, the clavicle, and the upper limbs[8] and it was suugested that it can be used as a new presentation part of BCU devices even at a distant parts of the body, i.e., not the head [8]. However, there are many unclear points in details of perceptual characteristics and propagation mechanism in such ditantly presented BCU.

In this study, in order to acquire useful information on elucidation of perceptual characteristics and propagation characteristics, acceleration of vibration in the external auditory meatus caused by distantly presented BCU were measured.

2. Methods

2.1.1 Participants. Seven male adults (21–22 years) who had no history of deficits of hearing functions participated in the experiment.

2.1.2 Stimulus location. BCU stimuli were presented to the following parts of the body (**Fig. 1**) by a piezoelectric ceramic vibrator (Murata Manufacturing MA40E7S).

(1). Mastoid process of the temporal bone
(2). Sternocleidomastoid muscle
(3). Clavicle
(4). Acromial process
(5). Brachialis muscle
(6). Brachioradial muscle
(7). Substernal region
(8). Thoracic vertebrae

To the mastoid process, the vibrator was pressed using a head band with a clamping pressure of 5 N. For other locations, an elastic band was used to hold the vibrator. Pressures of presentation were 2N for

Fig. 1 Placements of the vibrator

the sternocleidomastoid muscle and 5 N for the other locations.

2.1.3 Procedure. The participants were instructed to sit on a comfort chair in an anechoic chamber and to relax. According to previous studies[9, 10], the acceleration sensor (Ono Sokki NP-3211) wrapped in a 10-mm diameter urethane material was inserted in the left ear canal, and the acceleration of vibration generated by the 30-kHz BCU tone in the external ear canal was measured for 5 seconds. The acceleration signal was amplified by an amplifier (Ono Sokki PS-1300) and taken into a PC. For each measurement, the vibrator was detached and replaced. The frequency spectrum was calculated from obtained signals.

3. Results

Peak of the spectrum corresponding to the stimulation frequency (30 kHz) was clearly confirmed at all tested body parts. On the other hand, no significant peak other than 30 kHz was confirmed. **Fig. 2** showed the peak value (relative to the mastoid process) obtained for each parts of the body. As the stimulation part moved away from the head, the acceleration of the vibration tends to attenuate.

On the other hand, the acceleration of the vibration is larger when presented to the thoracic vertebrae which is relatively distant from the head than the acromial process which is close to the head. Moreover, although the distance from the thoracic vertebrae and the substernal region were almost equal, the acceleration was larger for the thoracic vertebrae than the substernal region.

4. Discussion

When presented to the mastoid process, the BCU pure tone is perceived as sound with a pitch of approximately 8 to 16 kHz[11], but any significant components other than the stimulation frequency has not been confirmed in measurements on/around the head[9, 10]. In the current experiment, any spectrum peaks other than the stimulation frequency were not be confirmed for all presentation sites. The results strongly indicate that even if the BCU pure tone is presented distantly, significant amount of audible sounds is not generated in the propagation process in the body.

A larger peak was obtained in the thoracic vertebrae distant from the head than the acromial process and the substernal region. This result shows that the transmission efficiency to the ear canal differs depending on the presentation parts. The trunk and head are connected via a relatively thick neck, whereas the propagation efficiency of the upper limb may be decreased because its propagation path is narrow.

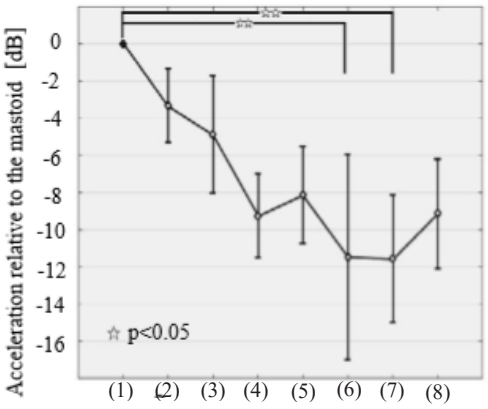

Fig. 2 Acceleration for the 30-kHz-component measured at each location relative to that of the mastoid.

5. Conclusions

Acceleration in the external auditory meatus caused by distantly presented BCU were measured. The results showed that no significant components other than the stimulation frequency were detected at all. Although the acceleration tended to decrease depending on the distance from the external auditory meatus basically, other anatomical conditions seem to affect the results. The detailed analysis of the propagation pathway seems to be necessary.

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Email:s-nakagawa@chiba-u.jp