Bone-Conducted Ultrasound

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Bone-conducted ultrasound (BCU) has unique characteristics since ultrasound is audible when it is presented through bone conduction. The most interesting is its perception in patients with profound deafness. Some patients can perceive it and discriminate speech-modulated BCU. Previous reports have suggested that BCU can be used for a hearing aid or tinnitus sound therapy.

bone conduction | ultrasound | ultrasonic perception | high frequency sound | profound deaf | tinnitus

1. Introduction

The audible frequency range of the human ear is between 16 Hz and 24 kHz [1], and a sound above this frequency range is referred to as "ultrasound." In contrast, ultrasound, whose frequency ranges up to at least 120 kHz, can create an auditory sensation when delivered via bone conduction (BC) [2][3][4]. Previous studies indicated that middle ear impedance might prevent ultrasound transmission via air conduction (AC) [3][5]. Other previous studies have suggested the generation of audible sound due to a nonlinear process in BC [4][6]. If a generated audible sound is predominantly associated with the perception of bone-conducted ultrasound (BCU), the characteristics of the induced sensation should resemble those of the audible sound. However, the reported characteristics of BCU perception (ultrasonic perception) are unique and not always observed with the perception of air-conducted audible sound (ACAS).

Characteristics of Ultrasonic Perception

According to previous reports, the pitch of BCU resembles that of ACAS at frequencies of 8–16 kHz, independent of its own frequencies [3][4][6]. The dynamic range is very narrow and similar to that obtained in patients with a cochlear implant [7]. The most interesting unique characteristic is the perception in patients with profound deafness. Some of them can perceive BCU [8][9][10], which suggests the contribution of a unique perception mechanism different from that of ACAS. Lenhart et al. found that some patients with severe hearing loss could discriminate BCU stimuli modulated with speech [8]. Cochlear implants are usually required in patients with profound deafness [11][12]. If a speech signal is delivered with an ultrasonic hearing device, a profoundly deaf individual can recover speech perception without any surgical operation. To apply this method in clinical practice, the mechanism underlying its perception should be established.

2. Application of BCU for Tinnitus Treatment

Tinnitus is a common audiological disease, and the prevalence of continuous subjective tinnitus among adults ranges from 5.1% to 42.7% [13]. It negatively affects the quality of life [14], and the prevalence of depressive disorders in this population can be high, ranging from 10% to 90% [15]. However, the efficacy of pharmacological and behavioral interventions remains limited. Sound therapy and psychological approaches have become mainstream for treatment [16][17]. In sound therapy, patients regularly hear sounds using sound applications or sound devices, such as hearing aids, sound masking generators, or modified-sound/Notched-music devices [18]. These sound therapies cannot be conducted in patients with profound deafness due to the severity of their hearing deficits. In contrast, BCU may be utilized for sound therapy in patients with profound deafness because some of them can hear BCU [8][9][10]. In contrast with hearing aids, the predominant aim of sound therapy is the mitigation of the symptoms, not the improvement of speech recognition. Thus, BCU is available more easily for sound therapy in patients with severe hearing loss.

Tinnitus is temporarily masked by presenting a sound, and it is continuously reduced or disappears during the few seconds or minutes after the offset of the masker presentation. This continuous reduction or disappearance of tinnitus is referred to as residual inhibition (RI). RI has been regarded as a clinical index that reflects the degree of tinnitus inhibition [19]. Goldstein et al. found that 20–26 kHz BCU masked tinnitus in 52 patients [20]. They suggested that BCU may be effective in masking tinnitus [21]. However, they did not measure the RI. Koizumi et al. evaluated the RI induced by BCU in 21 patients with tinnitus [22]. The masker intensities of the 30-kHz BCU and audible sounds were set at the minimum masking levels of tinnitus plus 3 dB and 10 dB, respectively. The duration of RI induced by the 30-kHz BCU was significantly longer than that of the RI induced by the 4-kHz sounds. The peripheral stimulation characteristic of BCU probably contributed to inducing long RI durations. Considering the lower presentation of the BCU masker, these findings suggest that BCU suppresses tinnitus more effectively than ACAS.

Sound therapy is regularly administered during daily life. When a sound generation device is used for sound therapy, a generated sound is presented with an earphone for a defined therapy session. During the session, hearing can be disturbed by the generated sound. However, if BCU is used as the presented sound, it rarely affects hearing within the frequency range involved in daily conversation. In addition, ultrasound is delivered via BC, and the insertion of an earphone is not required. Thus, sound therapy utilizing BCU may minimize its influence on daily life and provide good benefits. Further studies on tinnitus therapy using BCU are required.

3. Conclusions

BCU is perceived in the basal turn of the cochlea. However, its perception mechanism is different from that of ACAS. The intelligibility for the speech-modulated BCU is comparable to that for the original speech signal in normal-hearing individuals due to the contribution of demodulation. Unfortunately, the lack of the contribution of demodulation to speech perception has to be taken into consideration in hearing impairment patients. The performance of the reported speech-modulated BCU in speech recognition is limited in patients with profound deafness, and further innovation may be required for clinical use. Regarding the application to tinnitus treatment, BCU devices have unique advantages. Unfortunately, the knowledge of BCU in this field has not been sufficient, and further study is required for its establishment.

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