

# Chapter 16

## Bone-Conducted Ultrasonic Perception: An Elucidation of Perception Mechanisms and the Development of a Novel Hearing Aid for the Profoundly Deaf

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### ABSTRACT

*Although the mechanisms involved remain unclear, several studies have reported that bone-conducted ultrasounds (BCUs) can be perceived even by those with profound sensorineural deafness, who typically hardly sense sounds even with conventional hearing aids. Interestingly, these patients appear to perceive BCUs as well as subjects with normal hearing. The perception of BCUs by the profoundly deaf has been objectively proven using magnetoencephalography (MEG). Furthermore, the author has identified both the psychological characteristics and the neurophysiological mechanisms underlying the perception of BCUs using psychophysical, electrophysiological, and physical approaches. In addition, the author has developed a BCU hearing aid (BCUHA) for the profoundly deaf. Remarkable results have already been achieved with this device, which enabled 42% of the profoundly deaf subjects in the trial to perceive some sort of sound and 17% of them to recognize simple words. These results suggest the feasibility of this device, but additional development and improvements are needed.*

### INTRODUCTION

Worldwide, there are several million profoundly deaf people who cannot hear even with the use of conventional hearing aids. Although cochlear implants, which are implanted into the tempo-

ral cranial bone and electrically stimulate the cochlear nerve, can restore hearing ability, the results obtained with this procedure are not always satisfactory. Presently, there are no hearing aids that sufficiently restore the sense of hearing in profoundly deaf patients.

Although the upper frequency limit of human hearing is believed to be approximately 20,000 Hz,

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## Bone-Conducted Ultrasonic Perception

several studies have reported that bone-conducted ultrasounds (BCUs) are audible (Gavreau, 1948; Phumphry, 1951; Bellucci, & Schneider, 1962; Corso, 1963). Indeed, BCU hearing in humans has been demonstrated in various pathological auditory conditions, including sensorineural hearing loss and middle ear disorders (Bellucci, & Schneider, 1962). BCUs are perceived even by profoundly deaf subjects who cannot sense air-conducted and bone-conducted lower frequency sounds even with conventional hearing aids (Lenhardt, Skellett, Wang, & Clarke, 1991). Although the mechanisms underlying the perception of BCUs remain unclear, several hypotheses have been proposed, including the idea that BCUs are transformed into low-frequency audible sounds (Dobie, & Wiederhold, 1992) and the idea that either cochlear hair cells (Phumphry, 1951; Dieroff, & Ertel, 1975; Ohya, Kusakari, & Kawamoto, 1985) or vestibular hair cells respond to ultrasounds (Bellucci, & Schneider, 1962; Lenhardt et al., 1991).

In 1991, Lenhardt et al. reported that BCUs modulated by speech sounds were somewhat intelligible (Lenhardt et al., 1991), which suggested that it might be possible to develop a novel hearing aid based on BCU perception. However, Dobie and Wiederhold disputed Lenhardt's results, which were obtained from subjective psychologi-

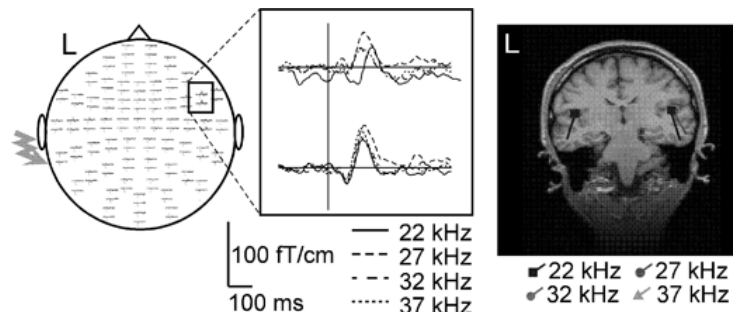
cal experiments (Dobie, & Wiederhold, 1992); ever since, there has been continuing controversy.

We have demonstrated and investigated BCU perception and have developed a novel hearing aid based on BCU perception (bone-conducted ultrasonic hearing aid: BCUHA) for the profoundly deaf. In this paper, we provide an outline of our studies on BCU perception and its applications.

## OBJECTIVE OBSERVATION OF BONE-CONDUCTED ULTRASONIC PERCEPTION

First, we performed neurophysiological experiments and provided objective support for Lenhardt's argument. Magnetoencephalography (MEG) (Hosoi, Imaizumi, Sakaguchi, Tonoike, & Murata, 1998; Nakagawa, Sakaguchi, Yamaguchi, Tonoike, Hosoi, Imaizumi, & Watanabe, 1999; Nakagawa, Yamaguchi, Tonoike, Hosoi, Imaizumi, Watanabe, 2000) and positron emission tomography (PET) (Imaizumi et al., 2001) revealed activation of the auditory cortex in response to BCUs both in profoundly deaf subjects and in subjects with normal hearing (Figure 1). Further, we showed that BCU amplitudes modulated by speech sounds were discriminated even by profoundly deaf subjects (Hosoi et al., 1998; Nak-

*Figure 1. Auditory cortical activities evoked by BCUs in a profoundly deaf subject. Left: Auditory-evoked magnetic fields in response to 22, 27, 32, and 37-kHz bone-conducted tone-bursts. BCUs elicit prominent peaks at a latency of approximately 100 ms (N1m response). Right: Sources of the N1m responses to BCUs estimated in the auditory cortices.*



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