Auris Nasus Larynx 40 (2013) 440–446

Contents lists available at SciVerse ScienceDirect

Auris Nasus Larynx

journal homepage: www.elsevier.com/locate/anl

Benefit of a new hearing device utilizing cartilage conduction

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ARTICLE INFO

Article history:
Received 18 October 2012
Accepted 11 January 2013
Available online 8 February 2013

Keywords:
Bone conduction
Non-osseous conduction
Soft tissue pathway
Aural atresia

ABSTRACT

Objective: Our previous study demonstrated that sound was effectively transmitted by attaching a transducer to the aural cartilage even without fixation pressure. This new method for sound transmission was found by Hosoi in 2004, and was termed cartilage conduction (CC). CC can be utilized even in hearing-impaired patients who cannot use air-conduction hearing aids owing to continuous otorrhea or aural atresia. A prototype hearing aid employing CC was investigated in this study.
Methods: Four patients with conditions such as continuous otorrhea and acquired aural atresia after surgery participated in this study. The CC hearing aid was fitted, and its benefits were assessed by audiometric tests and interview.
Results: Thresholds and speech recognition scores improved in all subjects. However, in subjects with continuous otorrhea, it was difficult to obtain the gains according to the target gains owing to their severe hearing loss and the limitation of the output level. On the other hand, unexpectedly large gains were obtained below 2 kHz in the patient with acquired aural atresia. These large gains were probably caused by soft tissue filling the postoperative space. No subjects complained of pain associated with the attachment of the transducer, although such problems are usually observed for a bone-conduction (BC) hearing aid. This feature is considered one of the advantages of the CC hearing aid.
Conclusion: The results of the audiometric tests and interview suggest that the CC hearing aid has potential as a useful amplification device for hearing disability. Unfortunately, if the soft tissue pathway is not involved, the current device is insufficient for the patients with severe hearing loss. The improvement of the output level will lead to develop a reliable CC hearing aid as an alternative to BC hearing aids or bone anchored hearing aids.

1. Introduction

Amplification by hearing aids is one of the most common approaches to compensate for hearing impairment, and air-conduction (AC) hearing aids are usually fitted. Although AC hearing aids are effective in most hearing impaired subjects, some patients experience difficulties in fitting. For instance, continuous otorrhea prevents the use of AC hearing aids because it damages them and occludes the sound bore. Furthermore, AC hearing aids and ear molds, which occlude the ear canal, may provoke or aggravate infection [1]. Otorrhea must be treated for AC hearing aids to be used. However, eliminating otorrhea is sometimes difficult. Patients with aural atresia, including both the congenital and acquired forms, present another challenge. For complete occlusion, earphones often cannot be inserted into the external auditory canal. Surgical repair has the possibility of improving hearing. However, maintaining the repaired external auditory canal after surgery is difficult, and the surgery sometimes results in lateralization, stenosis, or re-atresia [2,3].

In individuals with the above diseases, bone-conduction (BC) hearing aids or bone anchored hearing aids (BAHA) are usually applied as an alternative to AC hearing aids [4–6]. Because the transducer of BC hearing aids is affixed firmly to the head, patients are free of the aforementioned problems with AC hearing aids. Despite its merits, the BC transducer must be pushed tightly against the head if it is to function well, and continued use can cause skin induration, long-continued depressions in the skin, and discomfort [5]. BAHA were developed to avoid these disadvantages of BC hearing aids [7,8]. To wear a BAHA device, a titanium implant with an external abutment is embedded in the skull, and a sound processor is attached to it. This direct mechanical path to the skull enables vibrations to be more effectively transmitted without compression of the skin [9,10]. Unfortunately, surgery is required, and the portion of the implant exposed to open air can induce infection [11,12].

Hosoi found that clear sound can be heard when vibration signal is delivered to the aural cartilage from a transducer, which

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0385-8146/$ – see front matter
http://dx.doi.org/10.1016/j.anl.2012.12.003

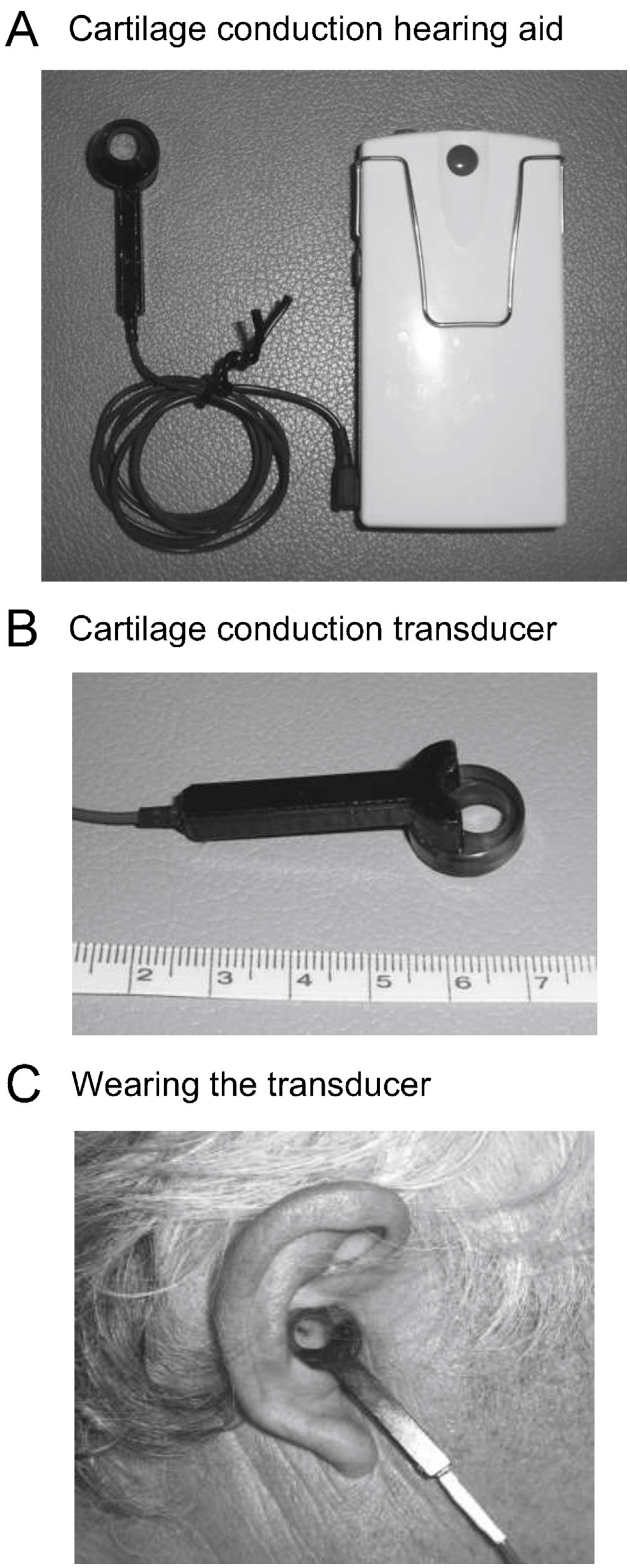

Fig. 1. Prototype cartilage conduction (CC) hearing aid and transducer. The prototype CC hearing aid is a body aid consisting of a microphone/amplifier complex and a devised transducer (A). The main body is equipped with a switch and a volume control. The digital signal processor is based on a commercial air-conduction (AC) digital hearing aid with functions, i.e., a nonlinear amplifier, noise canceller, and feedback management system. It can be adjusted with conventional fitting software for the original commercial AC hearing aid. (B) The devised CC transducer. A ring made of acrylic acid resin is glued to the transducer tip. The outer and inner diameters of the ring are 16 and 8 mm, respectively. The thickness is 5 mm. The total weight of the transducer is 6 g. The hole of the ring maintains the connection between the external auditory canal and the outside and contributes to avoiding the occlusion effect. (C) The CC transducer hanging on the cavity of the concha in a subject with acquired aural atresia (subject 3 in Section 2). It was fixed by its own weight without any instrument or additional pressure.

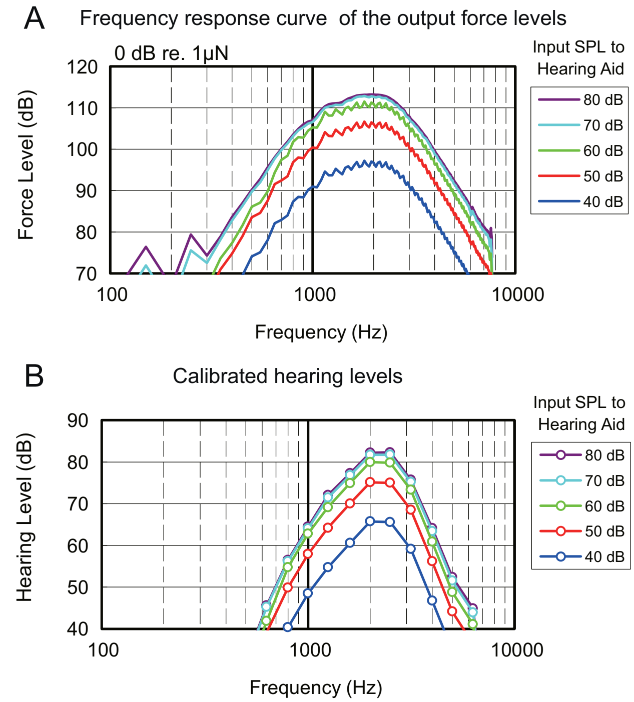

Fig. 2. Frequency response curves of the output force level from the cartilage conduction (CC) transducer (A) and calibrated hearing levels of the CC hearing aid (B) [14]. The frequency response curves were measured with an artificial mastoid (Type 4930; Brüel & Kjær, Nærum, Denmark). The calibrated hearing levels were calculated based on ISO 389-3 [15]. The gains of the CC hearing aid were set to maximum at all frequencies.

was termed “cartilage conduction (CC)” in 2004 [13]. Our previous study demonstrated that sound was effectively transmitted by attaching a transducer to the aural cartilage even without fixation pressure [14]. Unlike conventional BC, the attachment causes no pain, because the transducer is not necessarily fixed with pressure. Furthermore, this new form of conduction is possible without surgery. If sufficient benefit can be obtained by CC, it will have the potential to substitute for existing hearing amplification devices such as BC hearing aids and BAHA. In the previous study [14], hearing sensitivity by CC was measured using a devised transducer in a patient with congenital binaural atresia, who could hear sound well via CC. Fig. 1 shows the prototype hearing aid employing CC (CC hearing aid) developed in the previous study [14]. Its frequency response curve measured with an artificial mastoid (Type 4930; Brüel & Kjær, Nærum, Denmark) showed that the maximum output was obtained at approximately 2 kHz (Fig. 2). However, the benefits of the prototype CC hearing aid have not yet been assessed. In this study, the CC hearing aid was fitted in patients who could not use AC hearing aids for various reasons. Investigation of the benefits of CC hearing aids in these patients is expected to further elucidate the transmission pathway and allow the development of clinically applicable CC hearing devices.

2. Materials and methods

2.1. Subjects

Four hearing-impaired subjects with mixed or conductive hearing loss participated in this study. They had used hearing aids