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Comparison of High-Resolution Computed Tomography with Conventional Injection Fitting Method for Fabricating Hearing Aid Shells

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Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

Keywords
high-resolution computed tomography, hearing aid, image reconstruction, real ear measurement

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Prior to wearing customized hearing aids, an ear impression is generally required to fabricate an impression model for the construction of an ear mold, which plays a crucial role in hearing aid fitting. However, ear impression is an invasive operation, which can potentially lead to a certain risk, and these complications can adversely influence a patient’s physical and mental health. Recently, digital technology provides a novel approach for designing customized shells for hearing aids using 3-dimensional reconstructions of computed tomography (CT) data1,2 to eliminate the need to take an ear impression. This noninvasive technique provides an alternative for taking ear impressions. However, there are no data yet discussing the comparative effectiveness of fabricating hearing aid shells using high-resolution computed tomography (HRCT). Therefore, the current study aims to compare the practicality of ear impressions made by the traditional injective fitting method and of those manufactured through the HRCT technique.

Materials and Methods

Participants

Ten subjects ranging from 20 to 28 years old were enrolled in the study, which was approved by the Institutional Review Board of Chang Gung Memorial Hospital. Informed consent was acquired from all subjects, and the experiment was conducted in accordance with the Declaration of Helsinki. High-resolution CT of the temporal bone was performed using a 16-slice CT scanner (Somatom Sensation 16; Siemens, Erlangen, Germany).

Figure 1. (A) Behind-the-ear (BTE) impression mold obtained by high-resolution computed tomography (HRCT) image reconstruction, showing the cavum (a), cymba (b), and external auditory canal (EAC) (c). (B) Solid BTE impression mold obtained by conventional hearing aid fitting techniques, showing the cavum (a), cymba (b), EAC (c), and a bubble imperfection (d).

Three-dimensional rapid prototyping. The data obtained from CT scan DICOM imaging files were used as input data for the rapid prototyping (RP) system. These images were converted to stereolithographic (STL) files using computer-aided designing (CAD) software. We used ProJet HD3000 (3D Systems, Inc, Valencia, California) to build the 3-dimensional impression mold from multiple cross sections of the CAD model (Figure 1A).

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Ear Mold Making

This study compared the traditional pouring impression method with the 3-dimensional reconstruction method. The only difference was the technique applied at the casting stage: the traditional method uses an ear impression mold, whereas the present method uses a 3-dimensional reconstruction mold.

Geometrical Comparisons of Impression Molds

Solid impression molds of both ears of each subject were fabricated using conventional hearing aid fitting methods. Based on the required shape of a behind-the-ear (BTE) hearing aid, the impression molds of the external ear canals were then cut to the dimensions of the BTE impression molds. The volumes of these molds were measured using Archimedes principle. A linear equation of the form $y = y_0 + ax$ was used for data fitting.

Results

The cavum, cymba, and external auditory canal (EAC) could be clearly identified in both the mold obtained by noninvasive HRCT image reconstruction (Figure 1A) and the solid BTE impression molds obtained using the conventional hearing aid fitting method (Figure 1B). The geometries of these 2 molds were very similar, except for the presence of bubbles in the solid impression molds resulting from the method used. The HRCT impression molds were significantly smaller than the solid impression molds ($4054 \pm 902 \text{mm}^3$ vs $4765 \pm 984 \text{mm}^3$). However, the linear fitting to the data showed that there was a strong correlation between the volumes measured by the injection fitting method and reconstructed by the HRCT techniques ($r = 0.95$).

Discussion

The present study reconstructed the 3-dimensional ear model with HRCT images and made the ear mold through RP, replacing the traditional impression technique. The advantages of this method are that it is noninvasive and that image transportation, in combination with multiple revisions, can be achieved together on the same platform. The functionality of hearing aid shells made from the RP ear mold based on the real-ear measurement’s high-resolution digital images is similar to those produced using the popular traditional method. This demonstrates the comparative effectiveness of fabricating hearing aid shells using HRCT.

The present method gets its impression images through a CT scan, and this is more expensive than the traditional method. In addition, subjects are exposed to X-rays. Thus, this method should be reconsidered for patients who do not have medical insurance or whose illness precludes CT scan testing.

High-resolution CT of the temporal bone is commonly used to evaluate chronic supportive otitis media because of its high sensitivity to the presence of soft tissue disease and bone erosion. These factors prompted the present study to develop an alternative choice for those who need hearing aids but whose ear molds cannot be obtained using traditional techniques. Concerns about CT radiation mean that the traditional techniques cannot be entirely replaced with a reconstruction method based on HRCT imaging. Furthermore, traditional techniques are generally less time-consuming and more efficient and convenient for obtaining ear molds (Table 1).

However, the reconstructed digital impression can be stored, revised, designed, and transferred directly using PCs, which is convenient when reengineering the model of the silicone ear molds of hearing aids. This avoids the step of scanning the impression into a computer in the traditional method and thus can achieve the best possible fit.

The proposed technique for determining ear impressions using HRCT and medical imaging software can avoid the pain and ear blockage caused by the static pressure of injecting impression material into the EAC and can significantly reduce other potential complications of an invasive ear impression technique. However, concerns about CT radiation mean that the traditional techniques cannot be entirely replaced with HRCT imaging reconstruction methods. There is still an advantage to using the traditional impression method to create a mold, especially when the actual ear canal is available and accessible, and provides a better fit, reduced cost, and no radiation.

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Author Contributions

Chin-Kuo Chen, image reconstruction, results interpretation, and writing; Philip Kuo-Ting Chen, data collection and experimental design; Wen-Ta Chiu, experimental design; Wei-De Cheng, experimental assistance; Po-Hsiang Tsui, data analysis and writing.

Disclosures

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Table 1. Comparison of High-Resolution Computed Tomography (HRCT) with Conventional Injection Fitting Method for Fabricating Hearing Aid Shells

<table>
<thead>
<tr>
<th>Technique</th>
<th>HRCT Image Reconstruction</th>
<th>Conventional Injection Fitting</th>
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<tbody>
<tr>
<td>Storage</td>
<td>Digital</td>
<td>Entity</td>
</tr>
<tr>
<td>Modification</td>
<td>Repeatability</td>
<td>Nonrepeatability</td>
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<tr>
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<td>Invasive</td>
</tr>
<tr>
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</tr>
<tr>
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<td>High</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
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References


