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An Observational Study on Morphological Changes in the Ear Canal According to Jaw Movement

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Abstract

Background/Objectives: Useful technical details for manufacturing in-the-ear (ITE) hearing aids were obtained by analyzing morphological changes in the ear canal according to jaw movement.

Methods/Statistical analysis: The deviation between the cross-sectional area and the shape surface of the ear canal was analyzed by matching and aligning 3D scanned ear impressions for each condition, and the geometric accuracy was compared by the average mean (Avg error) and root mean square deviation (RMS error).

Findings: The cross-sectional area in the longitudinal direction of the ear canal was 1st bend 2.7%, mid 4.2%, 2nd bend 4.5%, and end 6.2%, indicating more change toward the eardrum. The degree of change could not be specified because it varied by measurement point and individual, but the maximum difference between closed and open conditions was 1.75mm in surface coordinates and 12.5mm^2 in cross-sectional area.

Improvements/Applications: Acquiring ear impressions is significant because morphological changes in the ear canal increase when manufacturing invisible-in-canal (IIC) and completely-in-canal (CIC) hearing aid shells sitting deep inside the ear.

Keywords: **Hearing aid, ear canal, ear impression, matching, shape comparison**

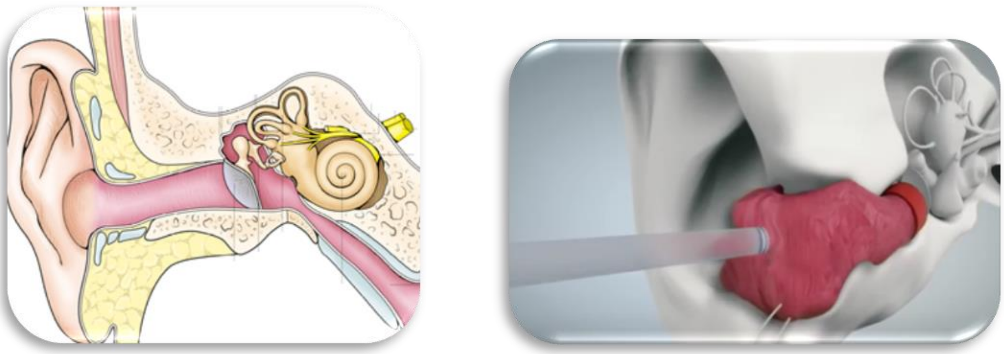
1. Introduction

Many people use hearing aids to overcome hearing loss. In-the-ear (ITE) hearing aids are worn in the ear canal to amplify the sound and match the individual's sound frequency [1]. The ear canal transmits, collects, amplifies, and resonates sound. It is of oval shape or has an S-shape, and is approximately 2.5 to 4 cm long. The ear canal is divided into two parts. The bony part (about 0.2mm) of the ear canal, where you fit ITE hearing aids, is thinner than the elastic cartilage part (about 0.5~1mm) and sensitive to pain [2-5]. Hearing aids help people with hearing loss, but when people use the wrong shape or size, they experience discomfort and acoustic feedback [6,7]. Hearing aids may also fall out when people talk or eat due to the movements of the ear canal. Such pain occurs because the hard hearing aid shell touches the soft tissue repeatedly and may increase as the structure of the ear canal changes by jaw movement. Therefore, the purpose of this study is to investigate the extent of morphological changes in the ear canal according to jaw movement. The tests involved acquiring ear impressions (the basic design required for manufacturing custom hearing aids) according to different jaw movement conditions, and analyzing the changes. Among related studies, Kim investigated the morphological features of 63 ear canals using 3D medical images, but only used data obtained under closed conditions. Therefore, this study observed changes in the ear canal in a dynamic state according to jaw movement [8-10]. According to a recent survey on hearing aid retailers (114 people), of all hearing aids sold, ITE hearing aids accounted for 60.5% to more than 70%, showing the significance of customization in user satisfaction [11]. As above, technical methods reflecting changes in the ear canal are important in the production of hearing aid using ear impressions, but there are limitations in precision because many areas still depend on the capabilities of technicians. Therefore, this study intended to obtain basic technical data for manufacturing hearing aids by acquiring ear impressions according to jaw movement and compare and observe morphological changes in the ear canal under each condition. Managing these causes will help resolve technical errors in manufacturing ear impressions and improve the satisfaction of hearing aid users.

2. Materials and Methods

2.1 *Need for research*

Custom hearing aid shells must be manufactured in the same shape and size of the ear canal to produce ITE hearing aids to overcome hearing loss. Acquiring ear impressions is essential during this process [Figure 1 (b)]. Therefore, this study investigated changes inside the ear canal according to jaw movement to improve the process of manufacturing hearing aids.



(a) Schematic diagram of the human ear canal (b) The process of acquiring ear impressions

Fig. 1(a) shows the structure of the human ear canal, eardrum, and cochlea, and (b) shows the process of acquiring an ear impression by inserting silicone in the ear canal.

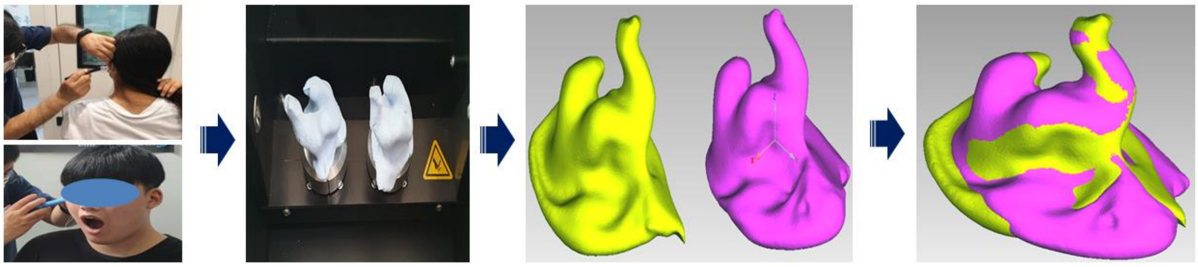
Figure 1. Images of conventional fixed auxiliary devices

2.2 *Equipment and materials*

Ear impressions were obtained from 10 healthy adults in their 20s (5 males and 5 females) without ear canal diseases in closed and open-mouth conditions. After 3D scanning (Duo scan touch, Cyfex AG, Germany) the acquired impressions from each individual in the same environment, the files were converted to STL (Stereolithography) format. The digitized ear impressions were matched and aligned by using 3D analysis software (Geomagic control 2014, 3D systems, USA) to measure, compare, and analyze the cross-sectional areas of 4 points and the values measured at 5 random coordinates (X, Y, Z points) [12].

2.3 *Method*

The process of acquiring the subjects' ear impressions, 3D scanning, converting to STL files, and matching and aligning the model were performed under the same environment [Figure 2]. The models obtained in both methods were aligned by matching the open-impressions based on the closed-impressions. The measurements were compared by using the cross-sectional area and random coordinate values from a 3D analysis software, and the geometric accuracy of the ear canals was compared by average mean (Avg error) and root mean square deviation (RMS error).

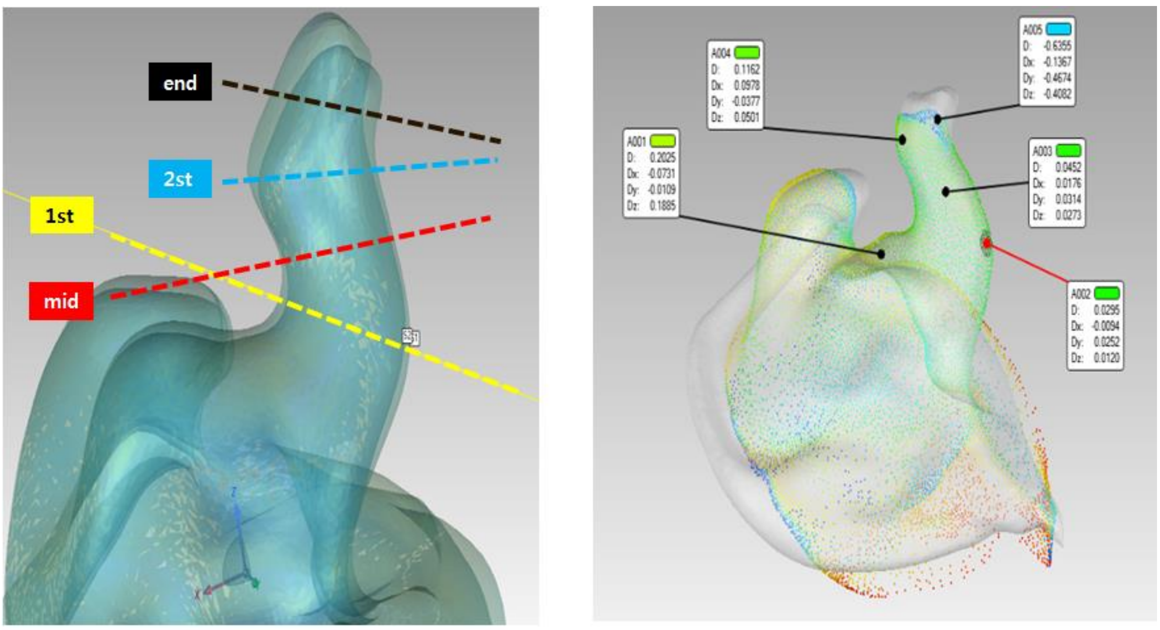


(a) Mouth closed & open (b) Ear impressions 3D scanner (c) Open & closed STL impression model (d) Automatic registration alignment

Fig. 2(a) shows the process of acquiring ear impressions, (b) scanning the ear impressions, (c) digital models of the ear impression, and (d) the process of matching and aligning the two models.

Figure 2. Digital matching and alignment process of acquired ear impressions

The cross-sectional area of the matched and aligned ear impressions were obtained by measuring the area of the line segment perpendicular to the ear canal surface at 4 locations: 1st bend (cross-section of Curve 1, yellow dotted line), mid (cross-section between Curves 1 and 2, red dotted line), 2nd bend (cross-section of Curve 2, blue dotted line), end (end of the impression, black dotted line) [Figure 4 (a)]. The ear canal surface was measured at 5 random locations from the outside of the ear canal toward the inner eardrum [Figure 4 (b)].



(a) Cross-sectional area measurement location (b) Point measurement location

Figure 3. The locations of the measured cross-sectional areas and random coordinate values

3. Results

3.1 *Changes in the cross-section of the ear canal*

The maximum and minimum difference in the cross-sectional area of the ear impressions aligned by digital modeling was 12.5mm^2 (2nd bend, 9-JMG-Rt) and 0mm^2 (2nd bend, 7-BSH-Rt). This is a 12.5% difference in area based on closed-ear impressions [Table 1]. The two acquired ear impressions showed a larger cross-sectional area at 23 closed and 16 open locations, and no difference in area at one location. The size and the shape were different depending on the location of measuring the ear canal of each individual and changed according to the subjects' characteristics [Figure 4]. However, the cross-sectional area of the ear canal showed changes in the order of 1st bend 2.7%, mid 4.2%, 2nd bend 4.5%, and end 6.2%, showing more morphological changes toward the eardrum [Figure 5].

Table 1. The cross-sectional areas measured at the same location of the ear canal

	Position	1st bend	Mid	2st bend	End
1-KGH-Lt	Close	38.71	25.77	33.27	30.36
	open	38.9	26.9	34.06	30.64
2-KGM-Lt	Close	56.28	34.69	32.46	30.57
	open	56.16	34.51	34.39	33.7
3-KJH-Lt	Close	83.59	73.43	71.64	63.34
	open	81.78	75.25	69.14	59.16
4-LBC-Lt	Close	81.48	65.79	65.79	46.24
	open	80.24	67.84	67.84	47.43
5-LHB-Lt	Close	49.32	30.71	32.01	20.29
	open	45.85	29.01	29.9	16.96
6-KTH-Rt	Close	79.79	80.57	84.2	65.8
	open	82.19	83.9	86.68	67.93
7-BSH-Rt	Close	99.06	89.97	74.67	48.02
	open	98.28	88.33	75.69	48
8-SSA-Rt	Close	72.03	53.38	43.08	37.34
	open	71.74	52.48	42.73	37.73
9-JMG-Rt	Close	89.27	73.66	76.34	71.56
	open	82.08	63.75	64.45	59.06
10-JGP-Rt	Close	52.43	43.8	46.61	43.05
	open	50.65	41.65	45.27	41.39

1st bend: cross-section of Curve 1, mid: cross-section between Curves 1 and 2, 2nd bend: cross-section of Curve 2, end: end of the impression

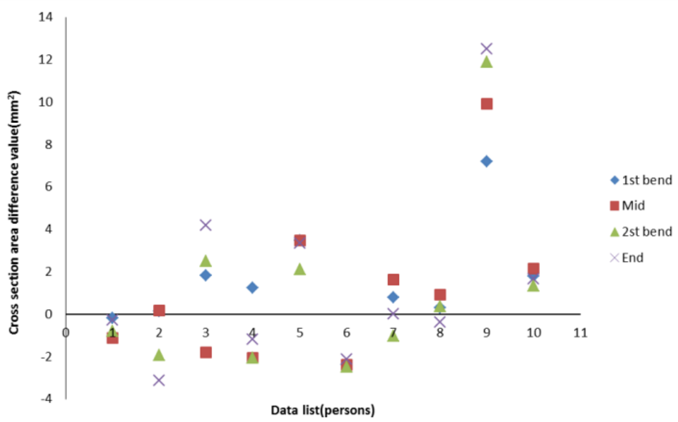


Figure 4. Graph of cross-sectional area difference at each location by individual

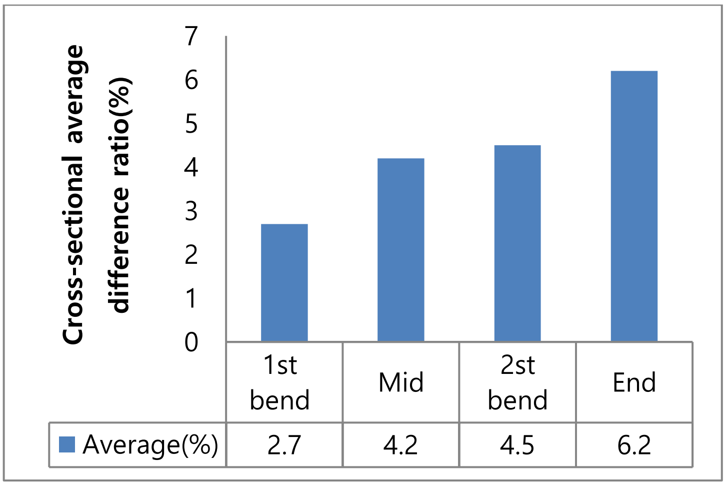


Figure 5. Cross-sectional area difference according to the measurement location of the ear canal

3.2 *Ear canal surface coordinate values*

The maximum and minimum distances between random coordinates at the same base line (red dotted line) were 1.75mm (p5, 9-JMG-Rt) and 0mm (p3, 1-KGH-Lt). Of the 50 coordinates tested, the surface values were high in 25 closed and 24 open locations, and the same coordinate values in one location. The ear canal surface showed significant differences according to each individual (9-JMG-Rt, 5-LHB-Lt), but the overall average difference was about 0.2mm [Figure 5].

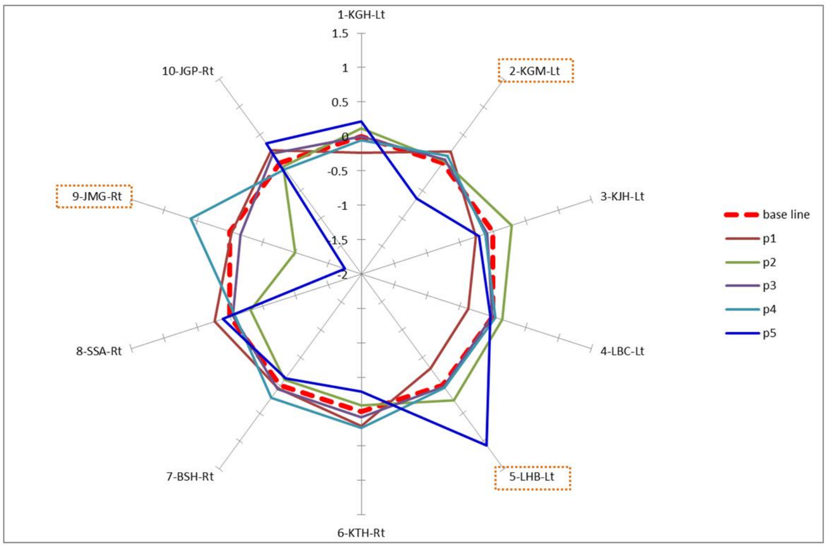


Figure 6. Individual deviation and root mean square error graph

3.3 *3D geometric accuracy of ear canals*

As a result of expressing the 3D geometric accuracy of the ear impressions by average mean (Avg error) and root mean square deviation (RMS error), both Avg and RMS were the highest in 2-KGM-Lt (1.13mm, 2.18mm) and the lowest in 1-KGH-Lt (0.38mm, 0.52mm) [Figure 6].

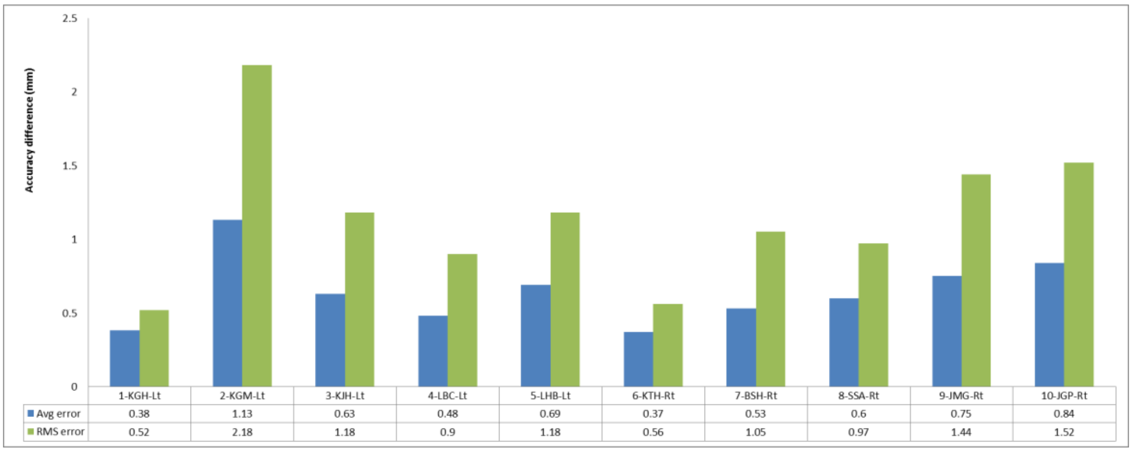


Figure 7. Difference in point mean on the feature surface

4. Discussion

As a result of matching and aligning each of the ear impressions acquired according to jaw movement and measuring 40 cross-sections and 50 surfaces, the measurements were numerically matched in 1 location each. This shows that the shape of the ear canal changes frequently when you move your mouth to eat and talk, and is also the reason why the shell and soft tissue frequently come into contact. Therefore, this may be a major factor in inducing pain (24%) according to a survey on the satisfaction of users wearing conventional ITE hearing aids [7,13].

The test results in this study also show that changes in the cross-sectional area in the longitudinal direction of the ear canal increase toward the eardrum (1st bend 2.7%, mid 4.2%, 2nd bend 4.5%, end 6.2%) [Figure 5]. Therefore, jaw movement causes more changes deep inside the ear canal, and this information should be considered when manufacturing IIC and CIC hearing aid shells.

As a result of measuring 50 random coordinates on the surface, the surface height was different in the closed or open conditions in 24 and 25 locations, except for 1 location. The difference ranged from 0 up to 1.75mm, showing various forms of change depending on the random locations and individual characteristics. There was also no consistency between the closed and open conditions in 5 locations of the same ear canal [Figure 6]. This shows the need for techniques considering movement variables when acquiring ear impressions.

The precision of the Avg error and RMS error of the shape of the 3D ear canals were verified to compare the values predicted by the model and the actual measurements. As a result, Case (9-JMG-Rt) showed maximum errors in cross-sectional area and surface coordinate measurements and the Avg and RMS were also high in Case (2-KGM-Lt) [Figure 7]. These results indicate the precision of the overall shape than measurements obtained from partial locations, and may not be significant in manufacturing customized hearing aids because the values include many parts other than the area required to manufacture hearing aids. However, this study has limited evidence to support this.

To examine anatomical features of the ear canal, Robert J. Oliveira et al. measured changes in the longitudinal axis of the ear canal according to jaw movement using a 1.5T MRI scanner and reported spatial differences in the upper/lower and front/rear external ear canal when the mouth opening level was around 10mm [14]. Boo Sung Hyun et al. measured the length of ear impressions using Vernier calipers while changing the conditions of the ear canal by mandibular movement [4]. Pirzanski investigated the facts and perceptions related to ear canal dynamics. The results showed no difference in shape according to gender, but found that 66% of the left and right ear canals were asymmetric [15]. By referring to the above, this study analyzed morphological changes in the cross-section and surface after converting the acquired ear impressions into 3D models. Although there were limitations in quantitatively controlling the degree of opening one's mouth and errors in the digital conversion process, the results showed the need for data on dynamic change when acquiring ear impressions. These tests and experiments will contribute to upgrading basic technology and improving the satisfaction of people using ITE hearing aids.

5. Conclusion

This study investigated morphological changes in the ear canal in mouth open and closed conditions, and the results showed more morphological changes toward the eardrum (1st bend 2.7%, mid 4.2%, 2nd bend 4.5%, end 6.2%). Although the degree of change in open and closed conditions could not be specified because it varied by each individual, the maximum difference in cross-sectional area and surface coordinates were 12.5mm^2 and 1.75mm, respectively. The test results showed more morphological changes toward the inside of the ear canal due to jaw movement, and this technical information should be considered in the process of manufacturing IIC and CIC hearing aid shells.

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