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Effect of the Change of the DICOM Image Thickness on the Shape Surface of the Hearing Aid Ear Shell Manufactured by 3D Printing

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Abstract: In this study, a new application technique that is different from the existing hearing aid ear shell manufacturing method was experimented by combining a medical image and 3D printing. The surface precision of the ear shell shape was compared based on the medical image for application to the hearing aid manufacturing technique. The external auditory meatus shapes with different Digital Imaging and Communications in Medicine (DICOM) image thicknesses were manufactured based on 3D printing and the surface precision and the difference in the modeling structure were compared. The results of the experiment showed that the size of the external auditory meatus shape had a problem with the Z-axis shape size during 3D image acquisition. The shape surface roughnesses were 0.453, 0.872 and 1.187 μm for the 0.5, 1.0 and 2.0 mm image thicknesses, respectively, indicating that superior surface roughness was obtained as the image thickness decreased. For the converted STereoLithography (STL) modeling, the distribution of the face became denser as the DICOM image thickness of the shape decreased. As for the difference, the 1.0 mm image thickness showed a 31.7% increase and the 0.5 mm image thickness showed a 94.9% increase, compared to the Unigraphics 2.0 mm. The results of this study showed that for the manufacture of hearing aid ear shell based on the DICOM method, superior surface and shape precisions were obtained as the DICOM image thickness decreased.

Key words: DICOM, ear shell, 3D printer, medical image thickness, surface precision, unigraphics

INTRODUCTION

The medical application technology that combined Digital Imaging and Communications in Medicine (DICOM) images and three-dimensional (3D) printing has developed in recent years. The latest studies such as the method of expressing the range and location of a tumor before and after treatment and the preparation of a surgical plan by manufacturing the surgical site of a patient before the surgery based on 3D printing after filming using 3D CT and MRI examination are convergence techniques based on DICOM images. (Go, 2017; Shin, 2017; Ferreira *et al*., 2014). The aforementioned studies are based on the results of the research suggesting that the three-dimensional structure of a human body can be identically made using 3D printing.

For the external auditory meatus which is in charge of auditory sense in our body, mass production of custom hearing aid is not available as the internal structure is different for each individual and high precision is required as the hearing aid is worn at all times. In the past, hearing aid was made by sampling the ear impression through injecting a material into the external auditory meatus of a human body. In the current technique, hearing aid is also made based on the sampled ear impression shape using digital 3D scanner and 3D printing (Shim and Yoon, 2014; Berman *et al*., 2012). According to the patent registration status in Korea, Kang developed a custom ear shell manufacturing method that designs and manufactures hearing aid ear shell using CAD software after sampling the ear impression using silicon material and scanning with a three-dimensional scanner in 2010 which is currently used as a leading technique in the domestic market (Kang, 2010; Alpern, 2010). According to the 2013 technology information, a method that designs the ear impression modeling of an individual by directly injecting a 3D Scanner into the human body without making ear impression is the hearing aid ear shell manufacturing method of Lantos Technologies which is a multinational corporation (Anonymous, 2017). This method has not yet been introduced and utilized in Korea but the application could be limited for young children, the case in which the external auditory meatus has a severely curved shape and those with inflammation within the external auditory meatus. As another method, Kim suggested the manufacture of hearing aid ear shell based on medical images through ‘A study on the novel modeling method for manufacturing hearing aid using three-dimensional medical image’s in 2016. Then, Kim also reported the relationship between the ear shell shape surface and the medical image thickness through 'A study on the effect of the STereoLithography (STL) file structure on the ear shell production for hearing aids based on medical image's (Kim, 2016, 2017).

In the present study, the surface precisions of the ear shells manufactured based on the same 3D printing were compared depending on the medical image thickness to present quantitative measurement values for the objective examination of the previous research conducted by Kim (2017). The purpose is to apply the results to a sophisticated hearing aid ear shell manufacturing technique that combined DICOM images and 3D printing in the future.

MATERIALS AND METHODS

Research direction: In the experiment, the hearing aid shape surface and the STL file structure were compared depending on the thickness of the medical image raw data for the manufacture of hearing aid ear shell using medical images and 3D printer and the schematic diagram is shown in Fig. 1: The results of the experiment were presented based on quantitative measurement rather than qualitative evaluation, compared to the previous research. (Kim, 2017).

Experiment equipment and material: For the medical image acquisition, 640 Multislice Computed Tomography (Aquilion ONE, Toshiba, Japan) was used and for the external auditory meatus extraction of the obtained medical image, a commercial 3D program (Intuition Solutions, Terarecon, USA) was used. In the case of the modeling, the measurement results were obtained using the STL View (Module Works GmbH), Matlab (MathWorks, USA), Rhinoceros (McNeel USA) and Unigraphics (Siemens, Germany) programs. In addition, the hearing aid ear shell printing was conducted using a 3D printer (Desktop Digital Shell Printer Plus Envision TEC, Germany) based on the same condition and the roughness of the printed shape surface was measured using a 3D digital surface roughness tester (Mitutoyo, Japan).

Experiment method: Using 0.5 mm temporal CT volume data and using the threshold value that is identical to the Hounsfield Unit (HU) of the anatomical structure (Choi and Kim, 2009). External auditory meatus with the same length (18.5 mm) was extracted based on the 0.5, 1.0 and 2.0 mm image thicknesses, respectively (Fig. 2 and 3). Then, the converted external auditory meatus STL files were merged again and the form and surface structure were compared. For the surface triangular structure on the

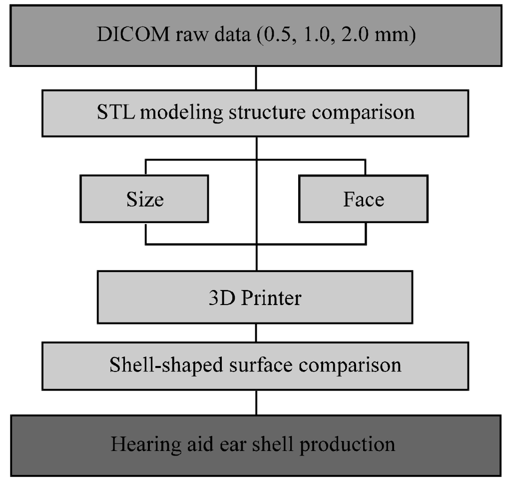

Fig. 1: Schematic diagram for manufacturing the external form of a hearing aid

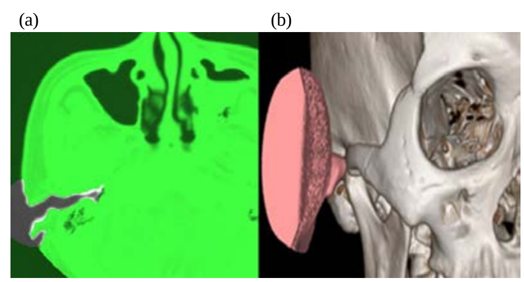

Fig. 2: External auditory meatus extraction process using the temporal CT volume data

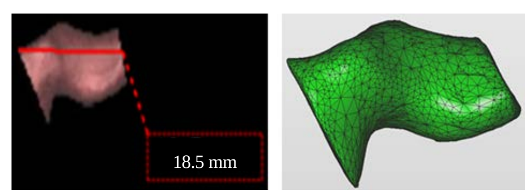

Fig. 3: Length of the major axis of the external auditory meatus edited from the 3D image and the converted STL file

file, the number of triangles (face) was measured using three programming languages and the shape surface was measured using a 3D digital surface roughness tester.

It represents the external auditory meatus extraction process using the threshold value that is identical to the Hounsfield Unit (HU) for the computer tomography volume data and the comparison relationship of the external auditory meatus extracted in the volume rendering condition.

RESULTS AND DISCUSSION

Difference in the three-dimensional external auditory meatus shape of the DICOM image: For the external auditory meatus STL modeling obtained using 0.5, 1.0 and 2.0 mm image thicknesses based on the DICOM image, the shape sizes in the X and Y-axis directions were identical but the sizes in the Z-axis direction varied depending on the image thickness. The shape sizes were in the order of 0.5, 1.0 and 2.0 mm image thicknesses, from the largest to the smallest (Fig. 4). As a result when the 3D printing was conducted using the same condition, the shape size in the Z-axis direction was visually distinguished (Fig. 5).

It represents the condition where the 0.5, 1.0 and 2.0 mm of the external auditory meatus edited as the same size have been merged based on the X and Y-axes and based on the X and Z-axes, respectively. In the case of the X and Z-axes, the size of the shape varied depending on the image thickness.

Analysis of the STL file structure: The number of triangles was examined by extracting the entire faces of the STL file structure using three programming languages (Fig. 6). For the 0.5 mm image thickness, the number was 3,976 and for the 1.0 mm image thickness, the number was 2,686 where the three programs showed identical values. However in the case of the 2.0mm image thickness, the number slightly varied depending on the program Table 1. Overall, the distribution of the triangular structure became denser as the DICOM image thickness of the external auditory meatus shape decreased. As for the difference, the 1.0 mm image thickness showed a 31.7% increase and the 0.5 mm image thickness showed a 94.9% increase, compared to the unigraphics 2.0 mm. For all the three programs, the number of faces increased as the image thickness decreased.

Measurement of the ear shell shape surface: The shape surface manufactured by the 3D printer was measured based on a contact method using the three-dimensional digital surface roughness tester (Mitutoyo, Japan). For the measurement position, the same spot at the entrance of the external auditory meatus was selected. The measured values were 0.453, 0.872 and 1.187 μm for the 0.5, 1.0 and 2.0 mm image thicknesses, respectively where the value decreased as the image thickness decreased (Fig. 7). This indicates that the image thickness is closely related with the surface roughness and the 0.5 mm image thickness showed relatively superior performance in the present experiment.

In the existing method based on ear impression sampling, the size shows a low precision in many cases

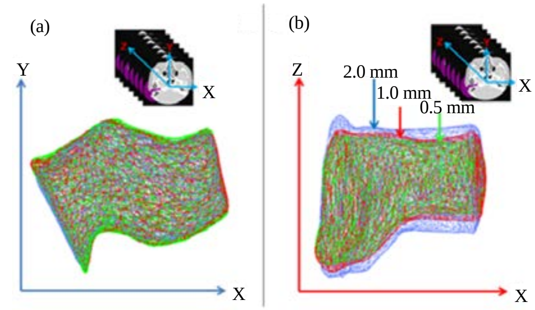

Fig. 4: Comparison of the size of the external auditory meatus shape for each DICOM image thickness

Fig. 5: Hearing aid ear shell shape manufactured by the 3D printer depending on the DICOM image thickness

Table 1: Total number of faces depending on the program and the DICOM thickness (unit: count)

Thickness (mm)	MATLAB	Rhinoceros	Unigraphics
0.5	3.976	3.976	3.976
1.0	2.686	2.686	2.686
2.0	2.040	2.037	2.039

due to the pressure of the external auditory meatus soft tissue, the error from the mixing of silicon with the foreign material within the external auditory meatus and the shrinkage/deformation during the manufacturing process (Oh, 2015).

In the DICOM method, there is no problem relevant to the existing ear impression manufacturing process but there is a problem with the shape size in the Z-axis direction during image acquisition. Accordingly, the image thickness should be sufficiently considered. This is thought to be due to the partial volume effect that occurs during the reorganization of the image volume data (Kang, 2010). Based on the human anatomy, the front/back directions (X and Y-axis directions) of the external auditory meatus showed the same shape size regardless of the image thickness but the top/down direction (Z-axis direction) showed relatively different sizes in the decreasing order of 0.5 mm (green), 1.0 mm (red) and 2.0 mm (blue) (Fig. 7). As hearing aid is used while being inserted into the soft tissue of the external auditory meatus of a human body, the size of the external shape could induce pain. Thus, the image thickness should be considered during the anufacture of hearing aid ear shell based on the DICOM method.

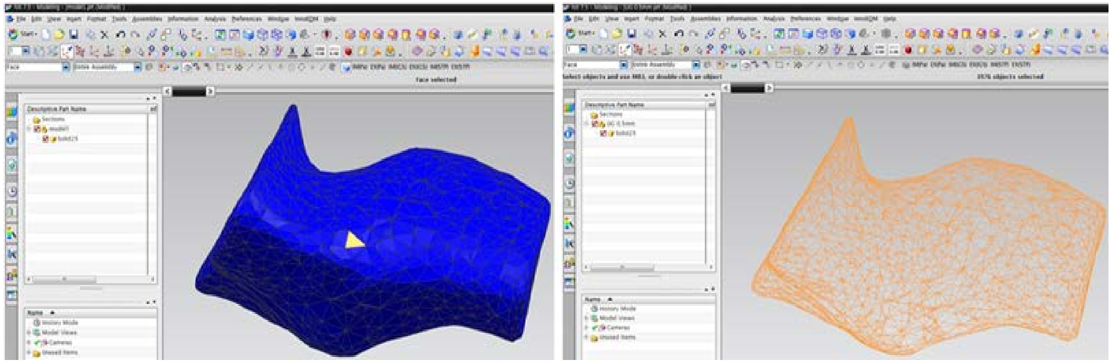

Fig. 6: Measurement of the total number of faces for the external auditory meatus shape by the program

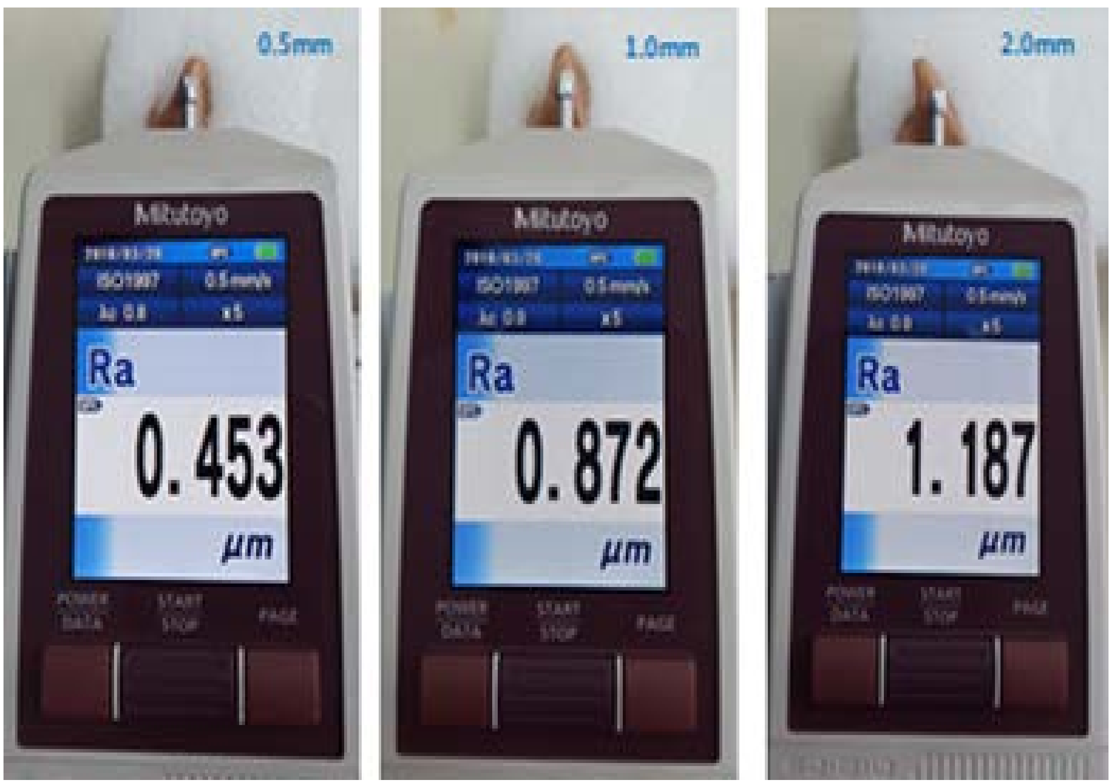

Fig. 7: Measurement of the surface roughness of the printed external auditory meatus shape

It represents the part that has not been edited during the three-dimensional editing of the 2.0 mm thick DICOM image (shown by the arrow). In a previous study, Kim examined the entire triangle distribution by indirectly measuring the numbers of intersecting points and maximum intersecting points for the STL file structure in the selective region of the extracted external auditory meatus modeling. However inthe present study, the entire face of the same shape was directly measured using different programs which increased the objectivity of the result. For the 0.5 and 1.0 mm image thicknesses, the numbers of triangles measured by the three programs were identical but for the 2.0 mm image thickness, different values were obtained (Table 1). It is thought that the number of faces for the STL file structure was affected because part of the image was not edited in the process of three-dimensionally extracting the external auditory meatus from the DICOM image and editing it as the same size (Fig. 8). In addition in the previous study, Kim (2017) compared the surface precision by magnifying the shape

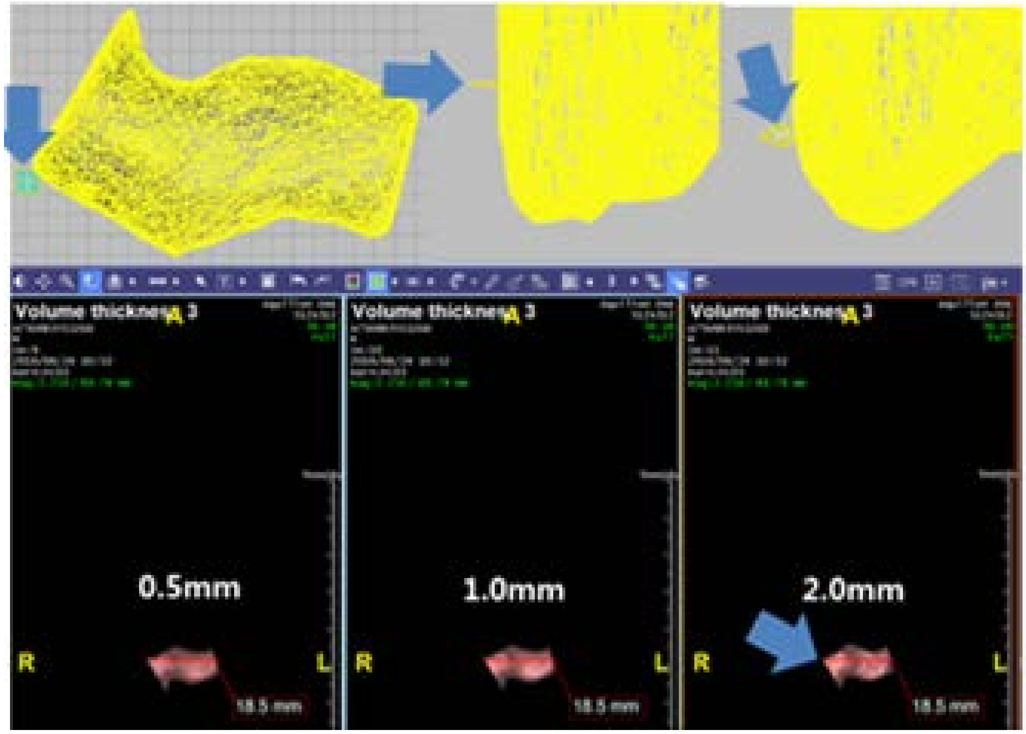

Fig. 8: The 2.0 mm part that has not been edited in the three-dimensional medical image

surface manufactured by the 3D printer using a digital microscope. However in the present study, quantitative comparison was enabled by using a measurement tool that can directly measure three-dimensional surface roughness (Mitutoyo, Japan). This increased the objective reliability through the quantitative comparison of the surface difference depending on the image thickness.

CONCLUSION

The 3D printer shapes were manufactured depending on the image thickness obtained from a three-dimensional medical image and two conclusions were drawn. First for the manufacture of hearing aid ear shell using the difference in the DICOM image thickness, the change in the size was more distinct in the top/down direction (Z-axis direction) rather than the front/back directions (X and Y-axis directions) of the human body. Therefore, the image thickness should be sufficiently considered during the manufacture of hearing aid ear shell using medical images. In the present study, the sizes were in the order of the 0.5, 1.0 and 2.0 mm image thicknesses, from the largest to the smallest. Second as the DICOM image thickness decreased, the triangular structure of the STL modeling became denser and the surface roughness decreased. This could maintain a smaller layered structure of the ear shell shape surface during 3D printing which could reduce the possibility of pain. In the present study, the surface roughnesses were in the order of the 0.5, 1.0 and 2.0 mm image thicknesses, from the best to the worst.

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