Anthropometry of External Auditory Canal by Non-contactable Measurement

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ABSTRACT

Human ear canals cannot be measured directly with existing general measurement tools. Furthermore, general non-contact optical methods can only conduct simple peripheral measurements of the auricle and cannot obtain the internal ear canal shape-related measurement data. Therefore, this study uses the non-invasive method, computed tomography (CT) technology, to measure the geometric shape of the ear canal to complete the anthropometry of external auditory canal. The results of the study show that the average height and width of ear canal openings, and the depth of the first bend for male are generally longer, wider and deeper than those for female. In addition, the difference between the height and width of the ear canal opening is about 40% ($p<0.05$). Hence, currently the circular cross-section shape of the earplugs should be replaced by an elliptical cross-section shape during manufacturing for better fitting.

Keywords: External auditory canal, computed tomography, anthropometry

1. INTRODUCTION

Article 21 of the Labor Safety and Health Act Enforcement Rules defines workplaces with noise levels greater than 85 dB as specially or highly hazardous working environments or as including specially or highly hazardous working operations. Article 300 of the Labor Safety and Health Facilities Regulations states that workers should wear effective earplugs, earmuffs, or other noise reduction apparatus in environments where they are exposed to noise levels greater than 85 dB for eight working hours a day or when the exposure level is over 50%. The soundproofing performance of earmuffs is superior to that of earplugs, especially for mid- to high-frequency domains, and although earmuffs conforming to the European standards (EN) provide better soundproofing effects, but the earplugs are more widely accepted by workers at actual worksites.

The requirements of EN 352-2 are concerned primarily with the physical and acoustic performance of the earplugs. It covers disposable, re-usable, custom moulded and headband ear-plugs. In the case of headband ear-plugs, the standard specifies sizing requirements which enable the great majority of the industrial population to be fitted satisfactorily by “medium size range” ear-plugs. Populations of other sizes may be accommodated by “small size range” or “large size range” ear-plugs, which are required to be accompanied by information regarding the range of sizes which they are designed to fit.

The United Kingdom commenced implementing noise reduction apparatus standards in 1994, and developed standards that countries within the Committee of European Standardization (CEN) must follow with regards to all European countries. The purpose of the hearing protection device is to reduce the damage caused by loud noises to workers and prevent subsequent hearing impairment. Factors that require consideration for hearing protection devices are the noise protection effects and whether the comfort level is accepted by workers. In addition to being able to reduce the noise level that workers are exposed to, ideal earplugs must not affect the workers’ experience of peripheral voices or sounds in the worksite, such as communication between staff, talking, and machinery and equipment operating conditions on work premises. An overprotection condition is more likely to cause ear canal discomfort, difficulties in conversation and verbal communication, and significantly reduces the workers’ willingness to wear earplugs, thereby causing earplugs to lose their hearing protection

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purposes. The external auditory canal (EAC) is a critical channel for sound reception (1) and the effect of aging on changes in the external shape of the ear canal is a frequently discussed topic in clinical practice (2). The human EAC wall can be categorized as two sections. The lateral 1/3 portion is comprised of cartilage, and the medial 2/3 portion near the eardrum is the bony structure. The average length of the adult ear canal is approximately 22.5 mm (3). The tympanometry was employed to measure the ear canal volume, with the human ear canal cross-sectional area presumed as a fixed value and the volume of the ear canal would not change as a result of variations in the soft tissue in the ear canal or changes in the eardrum (4). Zemplenyi et al. (5) developed a novel approach that used the optical method to measure the length between the opening of the ear canal and the eardrum. In 1993 the computer-aided tomography (CAT) to scan ear canals of cadavers for measuring the volume of the external ear canal and comparing the results with those obtained from the injection measurement method, and observed a 6.12% difference between the two methods (6). Shahnaz et al. (7) used tympanometry to measure tympanometric peak pressure and ear canal volume (ECV) and examine differences in the tympanum figure measurement values between Chinese people and Caucasians. The study included a total of 159 participants (303 ears) between the age of 18 and 34 years.

When the tympanometric examination is conducted at a frequency of 226 Hz, the ECV could be obtained according to the principle of energy reflectance (7,8). Voss et al. developed a non-invasive acoustic reflection measurement method to measure the ears of nine cadavers to calculate the ECV and volume of the middle ear cavity by applying ER. The results indicated that the measuring position affected the obtained measurement values. The downward trend of the reflective level of the ear is sensitive when the frequency is below 2000 Hz; however, it does not significantly affect the eardrum area. They also summarized that the ear canal measuring position, ear canal cross-sectional area, and middle ear cavity volume produced the three greatest variances (9). Al-Hussaini(10) indicated that the tympanometry measurement and using the Kamplex tympanometer was an accurate measurement tool for the ECV, and the accuracy of the external ECV was approximately 1.4 cm^3. Yost (11) stated that the length of the human ear canal was between approximately 2.3 and 2.97 cm.

The standards for earplug specification verification items vary among nations, and there is no standard size for earplugs. The ANSI S12.6 standards for U.S. hearing protection devices employ five plastic balls with different diameters: extra-small (7.26 mm), small (8.48 mm), medium (9.27 mm), large (10.46 mm), and extra-large (11.53 mm), to measure the ear canal diameter using the direct contact method. However, this standard does not specify any provision for differentiating earplug sizes. The content of earplug-related tests under the CNS national standard in Taiwan classifies large, medium, and small sizes (CNS T2012 8454, 1982).

This study employs a non-contactable and non-invasive measurement method to measure the EAC size of Taiwanese workers, and provides a reference for earplug options and fittings. Preliminary planning of this study entailed researching the ear canal of the Taiwanese labor population, using a non-invasive method to measure the geometric shape of the ear canal. This study employs high-resolution computed tomography (HRCT) and medical imaging software for experiments to calculate the ear canal opening external shape and volume for Taiwanese workers. The participants of this study are 40 Taiwanese workers (20 male and 20 female).

2. MATERIALS AND METHODS

This study uses HRCT (TOSHIBA/ Aquilionm, Tokyo, Japan) to obtain two-dimensional EAC images of the 20 male (average age: 25.5 y) and 20 female (average age: 24.67 y). Each CT image is composed of 512 × 512 pixels, with each pixel size set at 0.175 × 0.175 mm^2; slice thickness is 0.5 mm and voxel size is 0.175 × 0.175 × 0.5 mm^3. The study uses Amira® imaging software 4.1(Visage Imaging, USA) to display images for the external ear area of the skull’s temporal bone. The zoom and data window are used to adjust the minimum/maximum threshold values to display the EAC image, which includes: (a) cavum conchae, (b) ear canal opening, (c) ear canal, and (d) eardrum as illustrated in Figure 1. The brush and magic wand functions are used to circle and select the required sections for each HRCT, and the SurfaceGen application’s stack calculation tool is used to reconstruct the selected two-dimensional cross-section into a three-dimensional image of the normal ear canal as showed in Figure 2. This study was approved by the Institutional Review Board of Chang Gung Memorial hospital, and informed consent was obtained from all participants. The experiment was conducted in accordance with the Declaration of Helsinki.

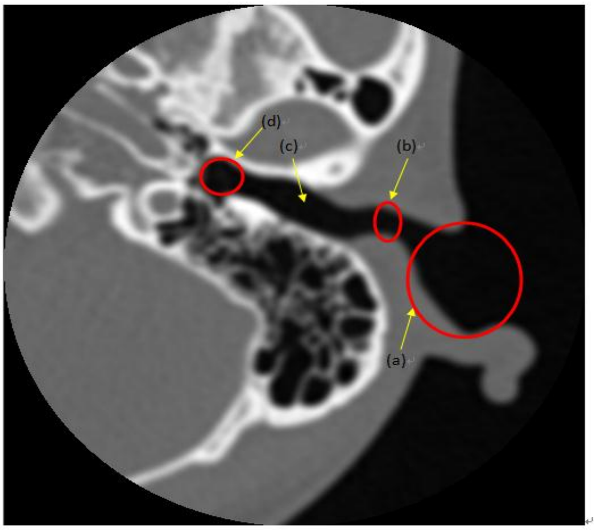

Figure 1 − Image of the external ear area of (a) cavum conchae, (b) ear canal opening, (c) ear canal, and (d) eardrum.

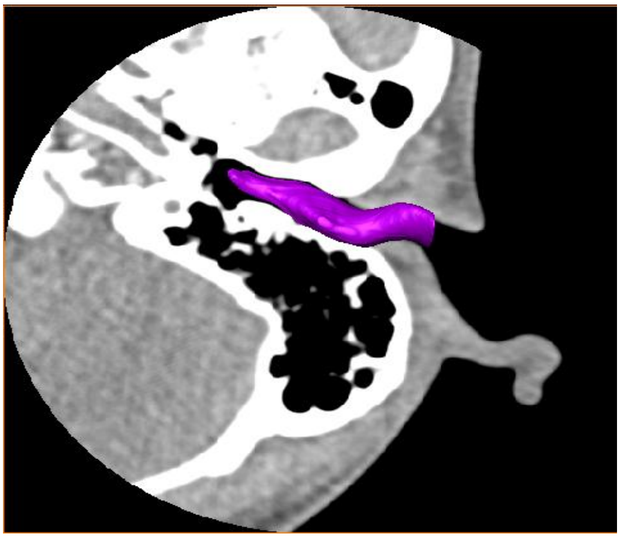

Figure 2 − Reconstructed three-dimensional ear canal image

2.1 Height and Width Measurement for the Ear Canal Opening

This study uses the Amira® medical imaging software to rotate the ear canal opening in three-dimensional image model to its sagittal plane. The application's anthropometry tool is then used to identify the longest part of the coronal plane as the base to obtain the baseline (a) and (b) for measuring the length of the ear canal opening. . Furthermore, the width of the ear canal, the widest part of the axial plane, which is perpendicular to the coronal plane, is measured according to the established base points (c) and (d) as shown in Figure 3.

2.2 Measurement of the Coronal Plane

In addition to using the imaging software for ear canal opening length and width measurements, we also divided the ear canal length measurement for the first bend, second bend, and upper and lower portions ear canal length according to the coronal plane. The measurement of the first bend upper ear canal length starts from base point (a) and extends to the first bend turn and base point (a1) using the projection method as shown in Figure 4. The first bend lower portion ear canal length is from base point (b) to the first bend turn and base point (b1). The second bend upper portion ear canal length starts from base point (a) to the second bend turn or base point (a2), and the second bend lower ear canal length starts from base point (b) to the second bend turn. The second bend upper portion ear canal length starts from base point (a) to the second bend turn and base point (a2), and the second bend

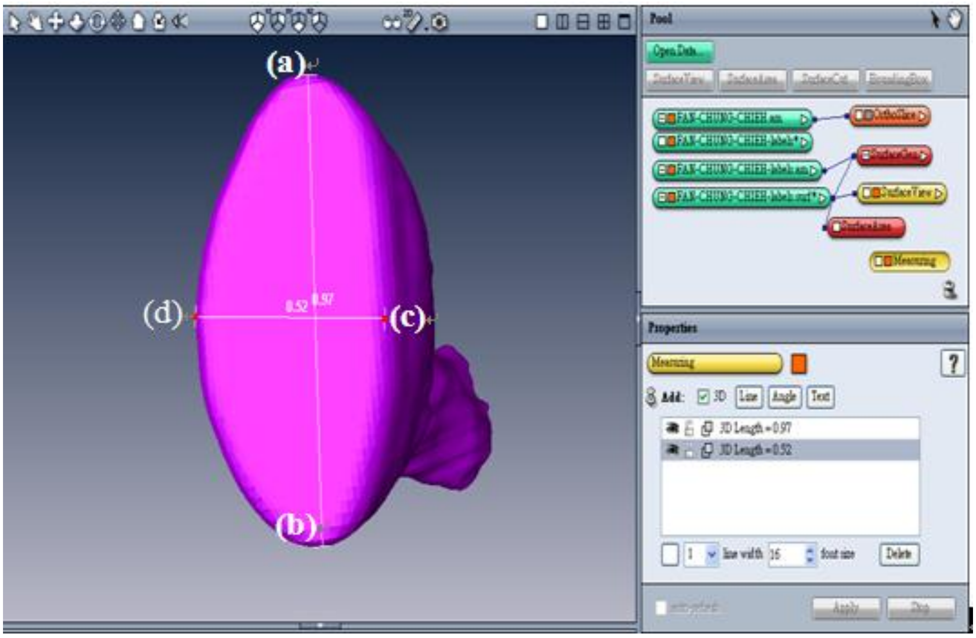

Figure 3 – Ear canal opening length measurement base points (a) and (b), and width measurement base points (c) and (d)

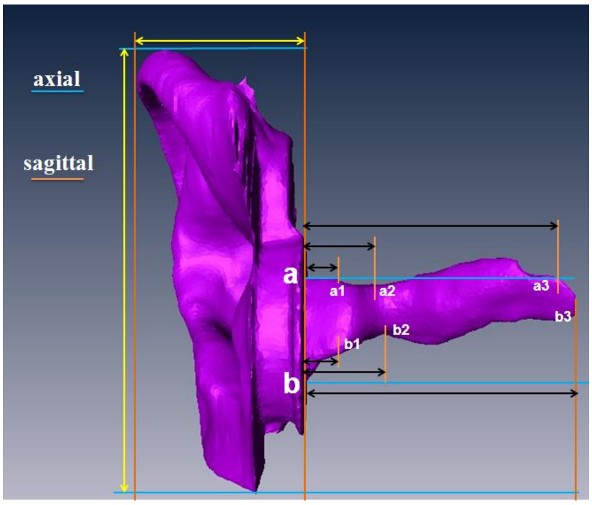

Figure 4 – Displaying the measurement method using the coronal plane

lower portion ear canal length starts from base point (b) to the second bend turn and base point (b2). The measurement of the entire upper ear canal length starts from base point (a) to the first bend turn and base point (a1), the second bend turn and base point (a2), and the eardrum as another base point (a3). The entire lower ear canal length starts from the base point (b) to the first bend turn and base point (b1), the second bend turn and base point (b2), and the eardrum as another base point (b3).

2.3 Measurement of the Axial Plane

The measurement of the anterior length of the first bend is from the base point (c) to the first bend turn and base point (c1) as shown in Figure 5. The posterior length of the first bend is from the base point (d) to the first bend turn and base point (d1). The anterior length of the second bend is from the base point (c) to the second bend turn and base point (c2). For the posterior length of the second bend starts from the base point (d) end at the second bend turn and base point (d2). The anterior length of the ear canal is from the base point (c) to the first bend turn and base point (c1), the second bend turn and base point (c2), and the eardrum as another base point (c3). The posterior length of the ear canal is from the base point (d) to the first bend turn and base point (d1), the second bend turn and base point (d2), and the eardrum as another base point (d3), as shown in Figure 5.

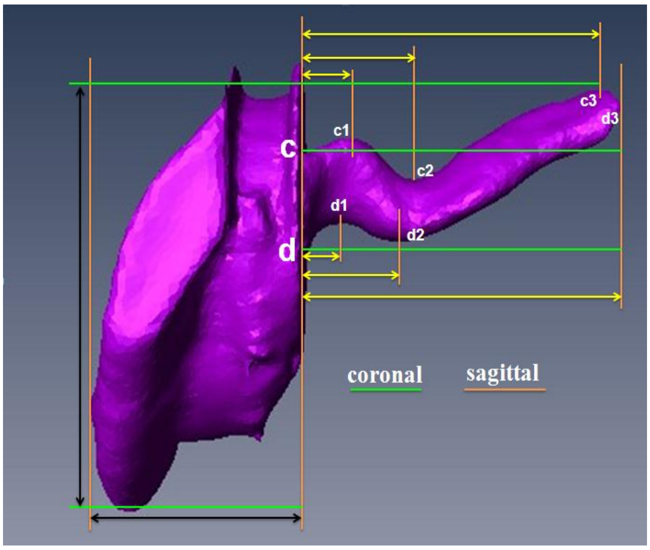

Figure 5 – Displaying the measurement method using the axial plane

3. RESULTS

In this study, the researcher performed CT for 20 male and 20 female and established the scan data files. However, some ear canals could not be reconstructed because of ear canal deformation. Therefore, the reconstruction process was completed for only 18 female and 20 male who participated in this study.

3.1 Ear Canal Opening

The obtained data indicates that the female's left ear canal openings have an average height and width of 0.91 and 0.63 cm, respectively, and their right ear canal openings have an average height and width of 0.92 and 0.63 cm, respectively. The difference between the height and width for female's left and right ears are 44.44% ($p<0.05$) and 46.03% ($p<0.05$).

The male's left ear canal openings have an average height and width of 0.96 and 0.68 cm, respectively, and the right ear canal openings have an average height and width of 0.96 and 0.67 cm, respectively. The difference between the height and width for male's left and right ears are 41.18 % ($p<0.05$) and 43.28 % ($p<0.05$). Figure 6 shows the height and width for both right and left ears are greater for the male than those of their female counterparts.

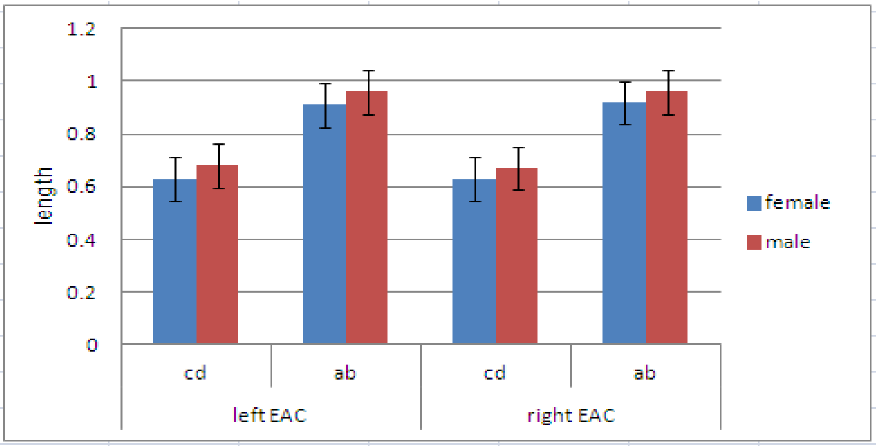

Figure 6 –Comparisons of the ear canal opening height and width between male and female participants. Note that ab is for the ear canal opening height, cd is for the ear canal opening width. (unit: cm)

3.2 First Bend Length

The average lengths of first bend upper and lower portions for female's left ear are 0.96 and 0.59

cm, respectively, and for right ear they are 0.97 and 0.59 cm. The lengths for the first bend upper and lower portions are 0.99 cm, 0.61 cm for left and right ear for male participants. The average lengths are 0.75 cm for the both left and right ears' first bend anterior and posterior portions for female. The average lengths are 0.78 cm for the first bend anterior and posterior portions for male's both left ear and right ear. Figure 7 shows that male's first bend upper, lower, anterior, and posterior lengths for both ears are longer than those of the female ($P<0.05$).

3.3 Second Bend Length

The average lengths of the female's left ear second bend upper and lower portions are 1.49 and 1.16 cm, respectively, and the average lengths for the right ear second bend upper and lower portions are 1.51 and 1.24 cm, respectively. The average lengths for the male's left ear second bend upper and lower portions are 1.64 and 1.2 cm, respectively, and the average lengths for the right ear second bend upper and lower portions are 1.63 and 1.24 cm, respectively.

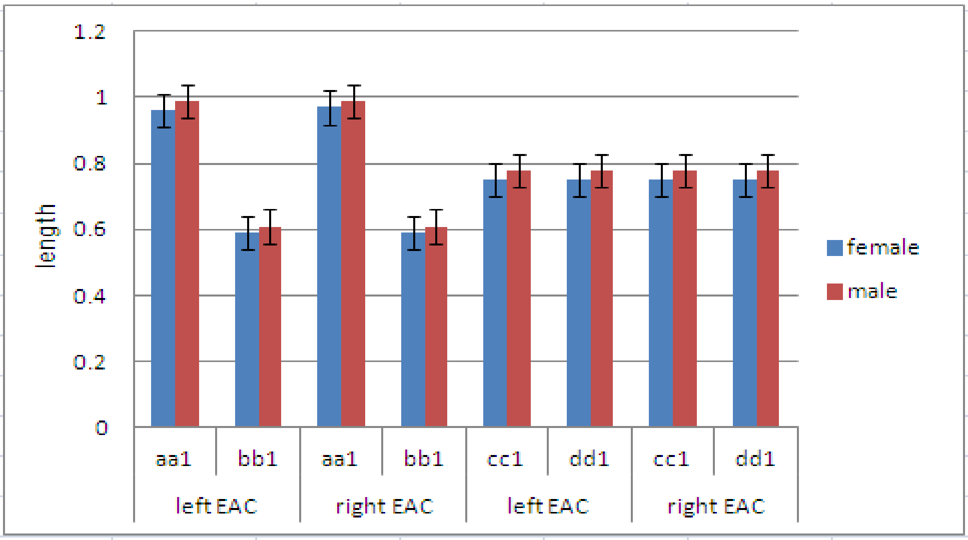

Figure-7 Comparison of the ear canal first bend length between male and female for both ears. Note that aa1 is for the first bend upper ear canal length, bb1 is for the first bend lower ear canal length, cc1 is for the anterior length of the first bend, dd1 is the posterior length of the first bend (unit: cm)

The average lengths of the second bend anterior and posterior for the female's left ear and right ear are 1.38 cm, 1.39 cm and 1.43 and 1.43 cm, respectively. For male's left ear second bend anterior and posterior portions are 1.39 and 1.38 cm, respectively, and corresponding lengths are 1.39 and 1.4 cm, respectively. Figure 8 shows that male's second bend upper and lower lengths of both the left ear and right ear are longer than those for female ($p<0.05$). The length for the right ear's second bend lower portion and left ear anterior and posterior lengths for male and female are similar. Finally, the right ear second bend anterior and posterior lengths for female are longer than those for male ($p<0.05$).

3.4 Total Ear Canal Length

The average length of left ear upper portions length for female is 2.52 cm, and the lower length is 2.26 cm. The average length is 2.55 cm for right ear upper portions, and it is 2.28 cm for right ear lower portions. For male participants, the average upper and lower portions length of left ear are 2.72 cm and 2.48, respectively. The right ear upper and lower portions length are 2.71 cm and 2.49 cm, respectively. Figure 9 shows that male's upper and lower lengths for ear canals in both ears are longer than those for female ($P<0.05$).

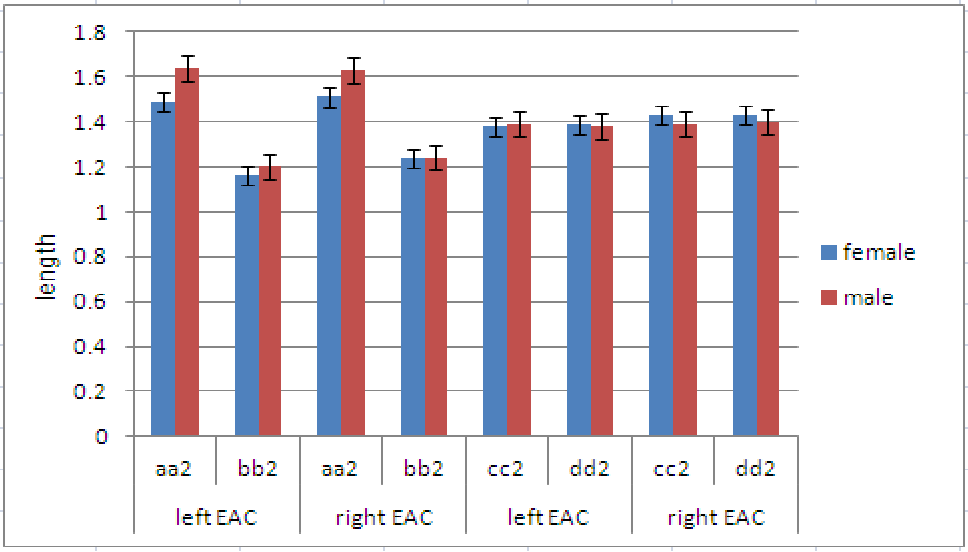

Figure 8. Comparison of the ear canal second bend length between male and female for both ears. Note that aa2 is for the second bend upper ear canal length, bb2 is for the second bend lower ear canal length, cc2 is for the anterior length of the second bend, dd2 is the posterior length of the second bend (unit: cm)

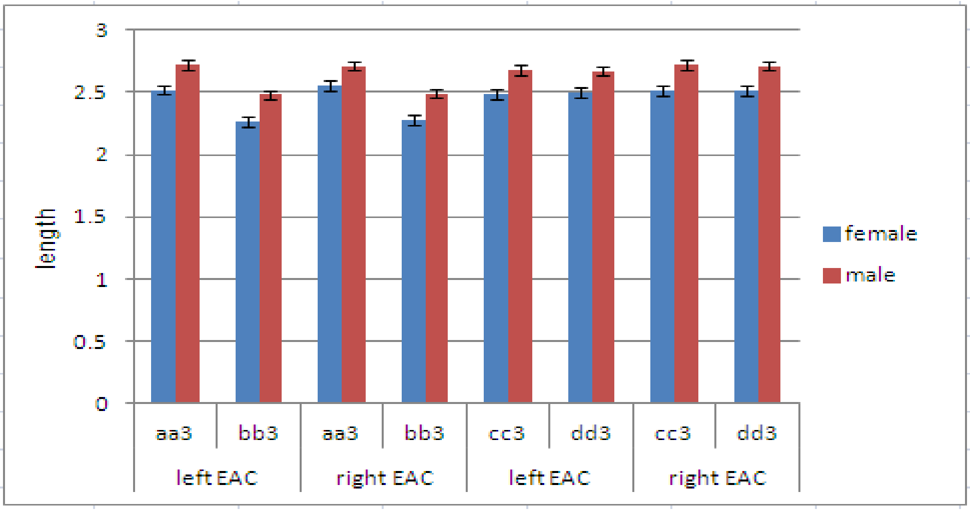

Figure 9−Comparison of the upper and lower full ear canal lengths for both ears between male and female. Note that aa3 is for t the entire upper ear canal length, bb3 is for the entire lower ear canal length, cc3 is for the anterior length of the ear canal, dd3 is for the posterior length of the ear canal. (unit: cm)

4. DISCUSSIONS

This study used CT scan technology to measure the anthropometry of human ear canals. In addition to conducting the ear canal shape measurements in a non-invasive manner, this research also established the ear canal measurement data of Taiwanese workers.

Under the current CNS standards, the range for small ear plugs is 0.5 to 0.7 cm, the range for medium ear plugs is 0.8 to 1.1 cm, and the range for large ear plugs is 1.2 to 1.4 cm. The results of this study indicate that, under the CNS standard, 9% of the participants are within the large size range, 88% within the medium size range, and 9% within the small size range for ear canal opening length. For the participants’ ear canal opening width, under the CNS standard, none of the participants are within the large size range, 21% are within the medium size range, 74% within the small size range, and 5% of the participants’ ear canal opening sizes are smaller than small size range. Therefore, for width, the researcher recommends that small size (S) should be less than 0.5 cm, medium size (M) should range between 0.51 and 0.85 cm, and large size (L) should be greater than 0.86 cm. For length, small size (S) should be less than 0.7 cm, medium size (M) should range between 0.71 and 1.3 cm, and large size (L) should be greater than 1.3 cm.

Because the ear canal opening heights and widths between Taiwanese male and female are different, the researcher recommends that the circular cross-section of the earplugs be replaced by an elliptical cross-section with a universal width between 0.63 and 0.68 cm and height between 0.91-0.96 cm during manufacturing.

5. CONCLUSION

This study established a three-dimensional ear canal model using a non-invasive method by CT and measured the geometric shape of the ear canal. The results of the study show that the average height and width of ear canal openings and the average depth of the first bend for male are generally longer, wider and deeper than those for female. Therefore, it is recommended to accommodate the differences in ear canal size between male and female workers. In addition, the difference between the height and width of ear canal opening is about 40% for female and male participants. The circular cross-section shape of the earplugs should be replaced by an elliptical cross-section shape during manufacturing. The results of this study can be used as an important tool for earplug development. Furthermore, it can be employed for basic statistics and research for otology, and can be adapted as a reference for worker earplug option and fit data. The results of this study can also give references for fitting and choosing ear plugs, achieve the objective of hearing protection for noise-generating worksites, reduce occupational injuries, and prevent workplace hazards caused hearing loss and impairment.

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