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The gray scale value of ear tissues undergoing volume-rendering high-resolution cone-beam computed tomography

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ABSTRACT

Objective: When the thresholds for VR reconstruction from multi-slice CT images are changed, problems develop when assessing pathologies in the absence of standardized thresholds. The advantages of CBCT include lower radiation exposure compared with other techniques and better visualization of small ear structures. However, a disadvantage is that the scanner provides unstandardized gray scale values, thus not CT numbers (Hounsfield units, HU).
Methods: We analyzed 88 sets of volume data obtained from temporal bones. The gray scale values were measured in aerated areas (two sites), along the ossicular chain (four sites) and in a bone area (one site) in the external and middle ears, and in soft tissue areas (five sites) and bone areas (two sites) in the inner ear.
Results: The standard male and female gray scale values were 2448–2970 and 2585–3091 for the aerated areas, 3248–4945 and 3359–5223 for the ossicular chains, 3368–4109 and 3371–4147 for soft tissues, and 4790–5776 and 5044–5959 for bone, respectively. Sex significantly affected the values ($p < 0.05$). Significant differences between aerated areas and ossicular chains, and between soft tissues and bone, were evident (all $p < 0.0001$).
Conclusion: Volume-rendering (VR) images obtained by cone-beam computed tomography (CBCT) can be standardized simply by using fixed thresholds.

1. Introduction

Volume-rendering (VR) multi-slice computed tomography (MSCT) ear images have been used to evaluate various pathologies including malformations, trauma, and anatomical alterations caused by surgery. Complex ear pathologies are difficult to understand when viewing two-dimensional (2D) images alone. However, three-dimensional (3D) VR MSCT images can be generated by combining 2D images that contain all necessary information, thereby revealing the anatomical features in detail. The attenuations of the ossicular chain and inner ear vary slightly among individuals. Thus, by changing thresholds within certain ranges, complete visualization of all relevant structures can be achieved by VR [1,2]. However, several reports have observed that when the thresholds are changed, problems develop when assessing pathologies in the absence of standardized thresholds (determined in healthy subjects). Thus, fixed thresholds are applied when exploring the ossicular chains [3,4].

Today, otologists commonly employ high-resolution cone-beam CT (CBCT) combined with flat panel detectors, a

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technique developed in the 2000s. In terms of image resolution [5], neither MSCT nor conventional dental CBCT scanners are satisfactory, because partial volume averaging renders the dimensions of various objects smaller than the slice thickness and the size of an individual voxel [6]. Both high-resolution CBCT and digital CT combined with a flat panel detector afford better definition of osseous structures within temporal bone. The cubic voxel dimensions are $125 \times 125 \times 125\ \mu m^3$ for high-resolution CBCT [7] and $150 \times 150 \times 150\ \mu m^3$ for digital CT using flat panel detectors [8]. Another advantage of CBCT is the lower radiation exposure compared with that of standard-dose MSCT, although CBCT is associated with limitations in terms of field-of-view and soft tissue contrast. Thereafter, high-resolution CBCT combined with a flat panel detector, in which the voxel dimensions are reduced to $80 \times 80 \times 80\ \mu m^3$, is optimal for detecting small bone defects such as cholesteatoma, examining the ossicular chain, positioning ossicular reconstruction prostheses, electrode arrays, and middle ear implants, and evaluating the chorda tympani [9–15].

Thus, the development of standardized gray scale (pixel) value thresholds for normal ears, particularly areas of aeration, the ossicular chain, soft tissue areas, and capsular bone, is essential. The use of standard gray scale value thresholds would simplify VR CBCT image interpretation and ensure the replicability of VR CBCT. CT thresholds are not applicable during reconstruction of VR CBCT ear images, because CBCT scanners lack the absolute CT values incorporated into MSCT. Rather, CBCT yields gray scale values that correlate with CT parameters but vary depending on the individual patient, side viewed, field-of-view, tube voltage, and tube current. Therefore, gray scale values cannot be standardized. In such situations, gray scale values are calibrated in Hounsfield units (HUs) using various phantoms employed in the dental field, because bone quality parameters and classifications are based primarily on bone density estimated in HUs [16]. However, such bone quality parameters and classifications are not available in clinical otological settings. Accurate and replicable VR CBCT images are essential when evaluating ear pathologies. Thus, standardized thresholds determined in normal ears are essential when CBCT is used for VR. Therefore, we determined gray scale values for various sites within normal ears, noting discrepancies in terms of the side and sites evaluated and patient sex, and we explain how to define fixed gray scale value thresholds.

2. Materials and methods

2.1. Subjects

A total of 88 sets of volume data (from 22 males, including 44 bilateral ears, with an average age of 49.2 ± 16.5 (range: 16–74] years and from 22 age-matched females, including 44 bilateral ears, with an average age of 46.9 ± 15.1 [range: 18–74] years) on temporal bones without inflammation, malformation, or a tumor were obtained using a high-resolution CBCT scanner (3D-Accuitomo F17®; J Morita Manufacturing Co., Kyoto, Japan) yielding images of voxel dimensions $80 \times 80 \times 80\ \mu m^3$.

2.2. Analytical procedures

We used inbuilt workstation software (i-view®; J Morita Manufacturing Co.) to derive gray scale values (Fig. 1). Since gray scale values along a line fluctuate even within the same side, we recorded the upper and lower limits of the software display. Seven sites in the external and middle ears and seven sites in the inner ear were selected for objective assessment of VR (Fig. 2). Table 1 shows why we chose these sites.

The CBCT scanning parameters were 90 kV, 8 mA, and a rotation time of 17.5 s. 2D-CBCT images were acquired at a thickness of 0.5 mm, a field-of-view diameter of 60 mm and height of 60 mm, and a matrix of 750×750.

2.3. Statistical analysis

We used the Mann–Whitney *U*-test, Spearman's correlation coefficient rank test, and Wilcoxon's signed-rank test, as appropriate. All analyses were performed using JMP statistical software (SAS Institute Japan Ltd., Tokyo, Japan). A p value < 0.05 was considered to reflect statistical significance.

2.4. Ethical approval

The study was approved by the Ethics Committee of Takanoko Hospital (Ehime, Japan).

3. Results

The gray scale values varied by the sites examined within ears and differed between aerated areas (i.e., the external auditor canal and tympanum) and the ossicular chains, and between soft tissue areas (i.e., the facial nerve, lateral

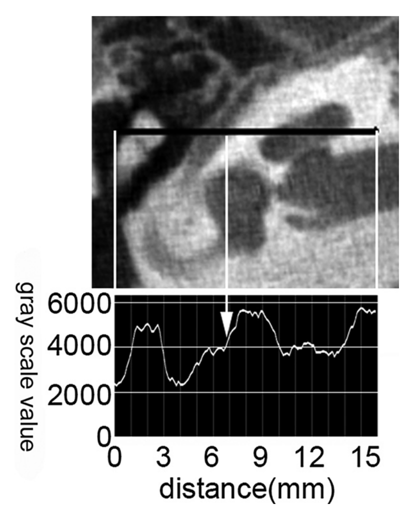

Fig. 1. Measurements of gray scale values.
A line graph displays gray scale values in the structures on a 16-mm line using a function of the software in the workstation. The first rise from 1 to 3 mm indicates the value of the ossicles, the second rise from 5 to 6.5 mm the facial nerve, third rise from 6.5 to 9.5 the bone of the capsule, and the trough from 10 to 14 mm the cochlea (e.g. the arrows indicate divisions between facial nerve and bone of the capsule).

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