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Accuracy in measurement of trabecular bone structure with dental limited cone-beam CT

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Abstract
Objective: The aim of this study was to evaluate the accuracy in measuring trabecular bone structure in zygomatic bone using dental limited volume cone-beam CT (CBCT).

Study Design: Ten zygomatic bone samples from 5 cadavers were examined by CBCT. After acquiring CBCT images, sections were produced and soft X-ray photographs were taken. Using these images, the ratio of bone area to total area of soft X-ray photographs and CBCT images was evaluated.

Result: The correlation coefficient between BA/TA of CBCT and soft X-ray images was found to be 0.83.

Conclusion: Though CBCT cannot generate a CT value, quantification of trabecular bone can be performed by converting CBCT images to a binary format with adequate form.

Key words: dental limited cone-beam CT, trabecular bone, zygomatic bone.

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Introduction
Usually, as a subjective evaluation method of bone quality, the classification method of Lekholm is used. As an objective method, classification based on Hounsfield units of the bone, so called quantitative CT, is often applied. CBCT is not able to be evaluated using Hounsfield units because its field of view is limited. CBCT is useful for diagnosis with its high resolution, but accurate quantitative evaluation with CBCT images cannot be performed directly.

The accuracy of CBCT in the measurement of distances has been investigated thoroughly. However, there are few reports in the literature on the analysis of trabecular bone structure. Therefore, the structural properties of trabecular bone were examined from CBCT images using image processing methods.

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Materials and Methods
Specimens: Ten zygomatic bones from 5 Japanese male cadavers were used (mean age: 70.6). In all specimens, 2 reference holes 2 mm in diameter were made using a 1.8 mm wide dental bur. The reference holes were set on the reference plane parallel to the Frankfort Horizontal plane and 10 mm above the jugale (Fig. 1).

CBCT images: A series of raw data images include zygomaticoalveolar crest, foramen infraorbitale, and reference holes were obtained using a CBCT (3DX Multi-image micro CT FPD, MORITA, Kyoto) at 5 mA and 80 kV with a single 360˚ rotation. The image slices were reconstructed with 0.125 mm isometric voxels.

Bone slice segments:
After CBCT scanning was completed, the zygomatic bones were removed from the cadavers. All specimens were dehydrated in an ascending concentration series of alcohol rinses and embedded in polyester resin (RIGOLAK, NISSHIN EM, Tokyo) without decalcification. The measuring plane was set as parallel to and 20 mm under the reference plane. The embedded specimens were placed in a micro-cutting machine (BS300CP, MEIWAFOSIS, Osaka), then 500 μm thick sections were cut from the measuring plane. The segments were placed on soft X-ray film (Fuji X-ray film, Fuji Film, Tokyo) and irradiated at 21 kV, 3 mA, for 7 sec and from a range of 35 cm. All soft X-ray films were digitalized using a transmission image scanner (ES-8500, EPSON, Tokyo).

Correlation between CBCT and soft X-ray images: The projection data was reconstructed with i-VIEW software (MORITA, Kyoto) and realigned using the reference holes. CBCT images corresponding to 0.5 mm thick segments were reconstructed at the same site. Median filtering and conversion to binary format by discriminant analysis was used to reconstruct the CBCT and soft X-ray images. Then, the regions of interest (ROIs) were designated at the same respective sites. The ROI was a square 25 pixels on a side without cortical bone. (Fig. 2) The ratio of the bone area to total area (BA/TA ratio) and the coefficient of correlation between CBCT and soft X-ray images were calculated.

Results
CBCT images: Using median filtering and conversion to binary format by discriminant analysis, it was possible to extract the data on bone elements from the CBCT images of zygomatic bone (Fig. 2).

Correlation between CBCT and soft X-ray images: As a result of the BA/TA measurements in each of 10 ROIs of CBCT and soft X-ray images, the average values were 48.0 ± 22.8% and 41.7 ± 22.3%, respectively. The correlation coefficient in BA/TA between CBCT and soft X-ray images was 0.8 in this study (Fig. 3).

Discussion
In order to evaluate the structural properties of bone, directly comparable data is required. In this study a quantitative evaluation method of trabecular bone structure was evaluated using CBCT images that are readily available for clinical diagnosis but are difficult to analyze quantitatively by only itself.

In a study using dry hemimandibles, the BA/TA ratio in CBCT images indicated higher values.
Fig. 2: CBCT image and visual explanation of image processing with an example. (Upper panels: soft X-ray images, lower panels: CBCT images) A: Region of interest (ROI) B: Median filtered image of A C: Binary image of B

Fig. 3: Relationship of the total bone area ratio (BA/TA) between CBCT and soft X-ray images.

It was suggested that this disagreement was caused by the loss of non-continuous trabecular bone in the bone slice segments, which had not been embedded in resin in order to avoid the occurrence of artifacts. In this study, all specimens were embedded in resin after CBCT images were obtained, so the loss of non-continuous trabecular bone was avoided. However, the BA/TA ratio in CBCT was still higher, and the coefficient of correlation of the bone ratio between CBCT images and bone segments was 0.8. Because of the production of artifacts, partly non-continuous trabecular bone in soft X-ray images became continuous trabecular bone in CBCT images and narrow spaces among trabecular bone in segments became linked in CBCT images. Conversely, although treated as artifacts in CBCT images after converting to binary format, narrow trabecular bone regions were subsequently missing. It is suggested that the elimination of artifacts from soft tissue and bone of craniofacial was not sufficient during image data processing. The signal to noise ratio (S/N) was affected by the mounting position, movement artifacts, metal artifacts, and so on. In addition, polymerization shrinkage might deform the trabecular bone structure in the bone segments to some degree. Therefore, the ratio of trabecular bone was higher in CBCT images. The conventional CBCT system consists of an X-ray tube and image intensifier (I.I.), but in this study a CBCT system with a flat panel detector (FPD) was used. Image deformation was reduced using the FPD. However, the CBCT system uses a two dimensional detector, which can be affected by scattered radiation.

A previous study analyzed the three dimensional internal structure of zygomatic bone and reported that the trabecular bone structure in zygomatic bone was different between dentulous and edentulous bone. The microstructure of the trabecular bone influences its mechanical properties. The CT value was influenced by the cortical bone thickness, so the CT value alone has limitations in evaluating trabecular bone structure. To evaluate the morphological properties of bone accurately, the analysis of trabecular bone was required. Therefore, an attempt to evaluate the internal structure of zygomatic bone using CBCT was a valuable exercise.

In conclusion, this study showed that it is valuable to evaluate trabecular bone with CBCT objectively. For accuracy, it is necessary to examine counter measures to artifacts caused by the mounting position, halation, motion, metal, etc.
References


