A Correction Method of CT Values Influenced by Partial Volume Effect

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INTRODUCTION

Recent researches on stress analyses of bones often utilize multi-sliced X-ray CT data to prepare the finite element models. In the stress analyses, CT values are utilized by estimation of Young's modulus. However little attention has given to partial volume effect of the CT data. The partial volume effect may cause low reliability in the analytical results because CT values on a bony part are changed by the effect. This paper proposes a method to correct CT values influenced by the partial volume effect.

CORRECTION METHOD

A sliced CT image is composed of many pixels. One pixel expresses a CT value reflecting to material property on the location. However, one pixel sometimes includes plural material properties of the object because of thickness of the sliced CT image. Figure 1 illustrates the phenomena. CT values are attenuated at the places where surface of the object is oblique to the direction of the CT plane. This phenomenon is called partial volume effect. In such places, shape of the object becomes fuzzy. This may lead to a mismatched finite element model.

We propose a method to correct CT values influenced by the partial volume effect. The correction method transforms CT values using the following regression function.

$$f_k(x) = a \cdot \exp[-\exp\{-k(x - x_c)\}]$$

Here, a is a constant value calculated from the difference between the maximum and minimum CT values in the image, x_c is a coordinate of a boundary point between the object and outer material, and k is a transform parameter which controls gradient at x_c. The exponential function is selected by reason of rapid change at the boundary point x_c.

Figure 2 shows the schematic diagram of the correction method. When the sequence of CT values along a line is obtained from a CT image, the transform parameter k_1 for fitting the sequence data is computed by the least-squares method. Next, difference between $f_{k1}(x)$ and the CT value is calculated at each point. $f_{k2}(x)$ is also calculated by the transform parameter k_2. Finally, the difference is added to $f_{k2}(x)$ as follows.

$$V_{new} = f_{k2}(x) + \{V_{CT} - f_{k1}(x)\}$$

Influence of the partial volume effect tends to appear not only at the surface of the bone but also at the boundary between different tissues such as cortical bone, trabecular bone, medulla and so on. For instance, CT values of the trabecular bone contacted with cortical bone may be higher than actual by the partial volume effect. Therefore the correction of the CT data needs not only rising up the CT values but also falling down depending on the situations of these tissues.

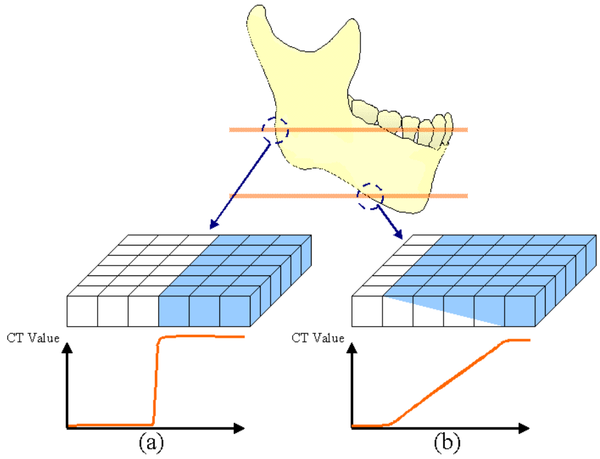


Fig. 1 Partial volume effect

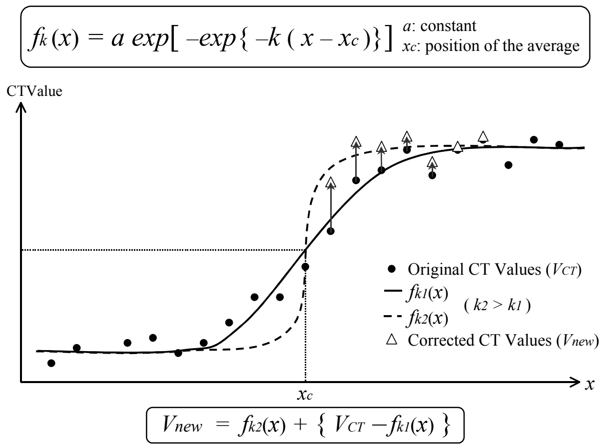
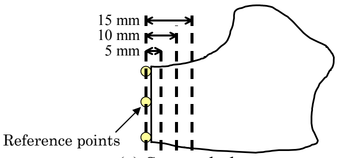


Fig. 2 Correction method of CT values

APPLYING TO A PIG'S FEMUR

Verification of the proposed method was examined using femurs of a pig. The medulla or other soft tissues adhering to the femurs were eliminated. CT images were scanned in orthogonal sections and oblique sections in 5mm increments from reference plane as shown in Fig. 3. To obtain the exact reference plane in the scanning, metal balls were attached to the cutting plane as reference points. CT images were taken under the conditions that slice thickness of the CT is 1, 2, 5 and 10mm. Then, the femurs were cut off at the scanned planes with a saw and the cross sections were observed. Figure 4 summarizes the photos of the cutting planes of the femurs and CT images of the same planes for the each slice thickness. Large slice thickness made the CT image ambiguous especially in the oblique sections.

(a) Perpendicular cutting plane (b) Inclined cutting plane



(c) Scanned planes

Fig. 3 Cutting planes of the pig's femur

Table 1 Thickness of the cortical bone [mm]

Slice thickness [mm]	Measured position			
	(A)	(B)	(C)	(D)
1	3.86	4.99	4.28	9.63
2	3.92	4.99	4.28	9.63
5	3.92	4.99	4.16	9.03
10	3.33	4.99	3.92	9.03
Actual thickness	3.65	5.45	4.60	9.55

The correction method was applied to these images. Figure 5 shows the computed images by the correction method. The shape of the cortical bone became clear. Thicknesses of the cortical bone were measured from the computed images and the actual bones. The thickness by the correction method was estimated from number of pixels corresponding to the cortical bone. The actual thickness was measured with a vernier caliper. Table 1 summarizes the thicknesses of the cortical bones at the four places as shown in Fig. 5.

The computed thicknesses of the cortical bone well agreed with actual measurements. Although corrected errors became larger as slice thickness increases, the errors were within the range from 0.03 to 0.68mm. Since the resolution of the CT image was 0.3566mm/pixel, the errors are estimated within two pixels. This means that the proposed correction method works well.

CONCLUSION

This paper proposed a correction method of CT values influenced by the partial volume effect. The correction method transforms CT values with a regression curve of an exponential function. The validity of the proposed method was confirmed using CT images of pig's femurs. The corrected thickness of cortical bones was well agreed with the actual measurement of the bone.

Young's modulus of a bone is computable from CT values. The correction method is expected to give reliable Young's modulus to an analytical model. Our next study is to examine the validity of the method on the viewpoint of mechanical characteristics of a bone.

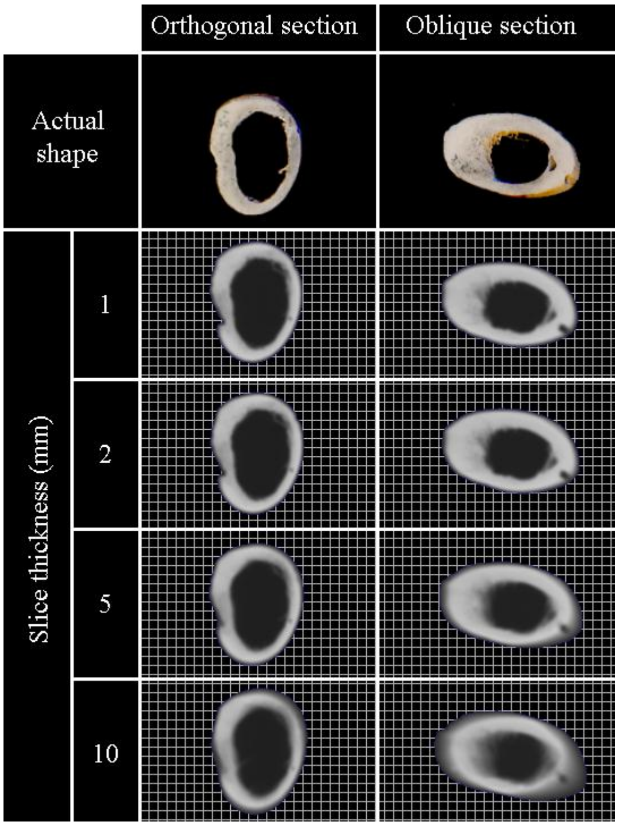


Fig. 4 CT images of the pig's femurs

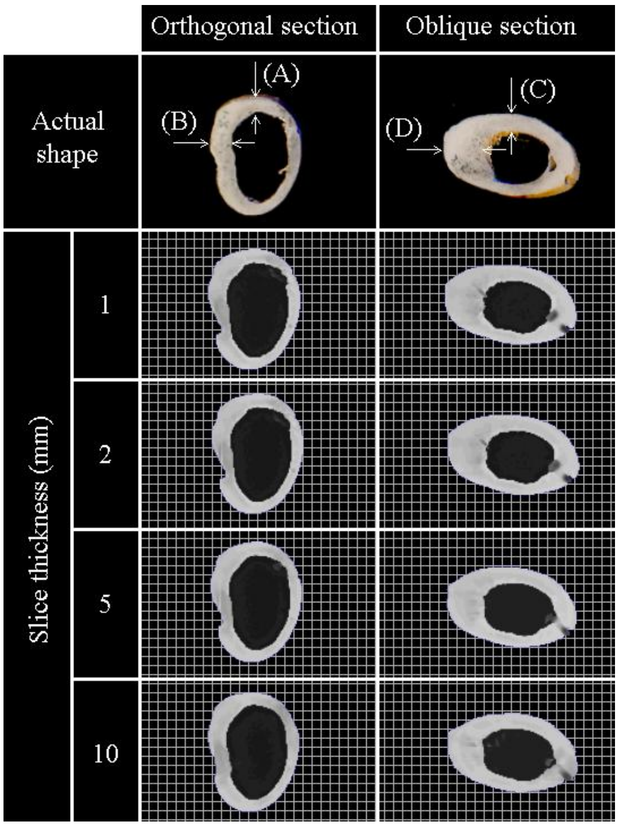


Fig. 5 Corrected CT images of the pig's femurs

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