Research Article

Biomechanical Analysis of Jaw Bone with Cyst Using CT-Image Based Finite Element Method

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Abstract

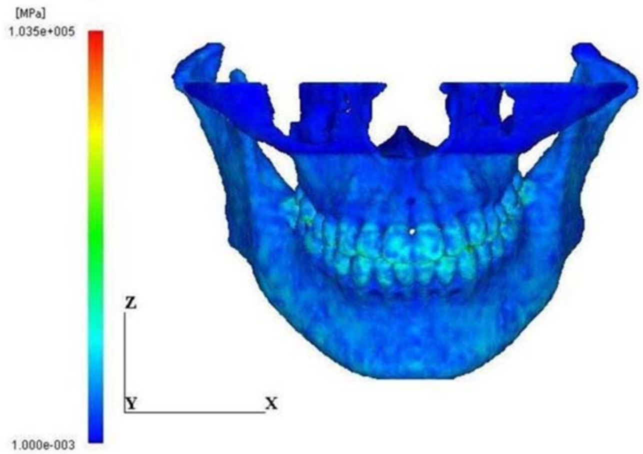
A three-dimensional jaw bone model consisting of maxilla and mandible was constructed using CT- images. The distribution of Young's modulus was also estimated from the bone density distribution. The developed model was then applied to analyze the effect of a spherical cyst located in the mandible on the mechanical condition in the jaw bone using the finite element method. An occlusion condition was used as the boundary condition by employing muscle forces. It was found that the strain energy density was concentrated in the several regions in the vicinity of the cyst, and the regions were generated by both tensile and compressive stress concentrations. It is thus concluded that this kind of 3-D modeling could clinically be used for predicting the risk of fracture of jaw bones.

Keywords: Dental biomechanics; CT-image based modeling; Occlusion; Finite element analysis

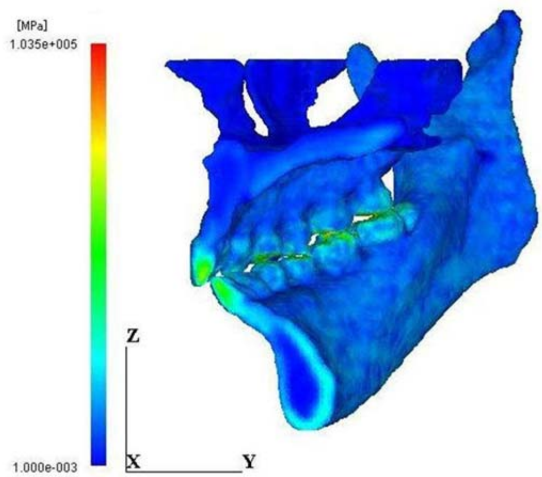
1. Introduction

CT-image based modeling has been developed to construct realistic bone models with their 3-D shape and structure and has effectively been applied to clinical problems in the fields of orthopedics and dental science [1-9]. In this modeling technique, a 3-D bone model is constructed from a series of CT-images by extracting the cross-sectional areas corresponding to the bone. Recently, the concentration of CT-value on the CT-images is successfully used to estimate the density of the bone and furthermore, the corresponding Young's modulus [6-9].

In the field of dental science, simplified bone models have mainly been used to analyze clinical problems, for example, the mechanical interaction between the bone and dental implants [10-13]. Recently, full mandible or maxilla models have been constructed using CT-images in order to assess the effect of complete bone structure on



(a) Anterior view

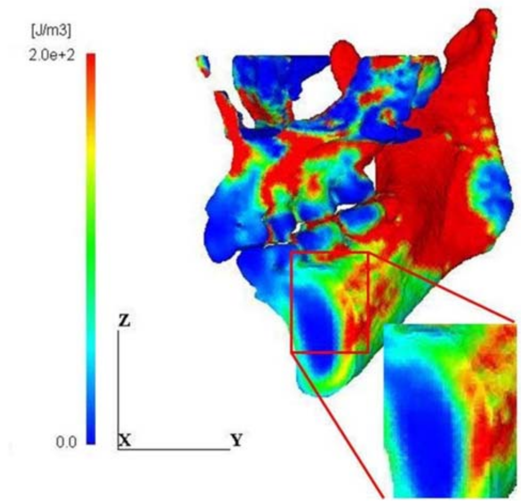


(b) Lateral view

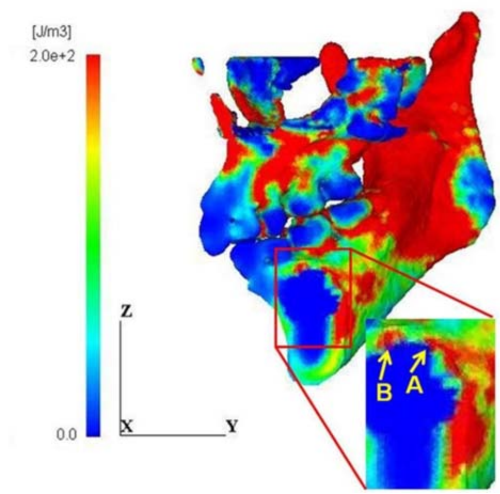
Figure 5: Distribution of young's modulus.

3.2 Distribution of strain energy density and principal stress

The distribution patterns of strain energy density for the normal model and the cyst model are shown in Figure 6. It is obviously seen that the concentration of the strain energy density in the cortical bone surrounding the cyst is more extensive and higher than that in the normal model. The cyst covered 90% of the cross-section and therefore, the thickness of the surrounding cortical bone became very thin, resulting in such high energy concentration. The maximum values of the strain energy density within the region surrounding the cyst are shown in Figure 7. It should be noted that the maximum value increased with increase of the cyst diameter and the maximum value for the largest cyst is thirteen times larger than that for the normal.



(a) Normal model



(b) Cyst model

Figure 6: Distribution of strain energy density.

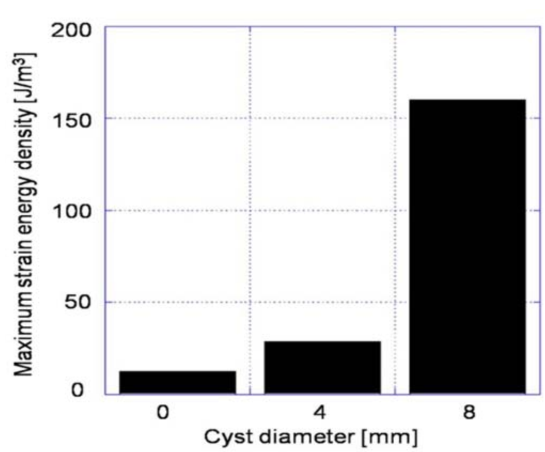
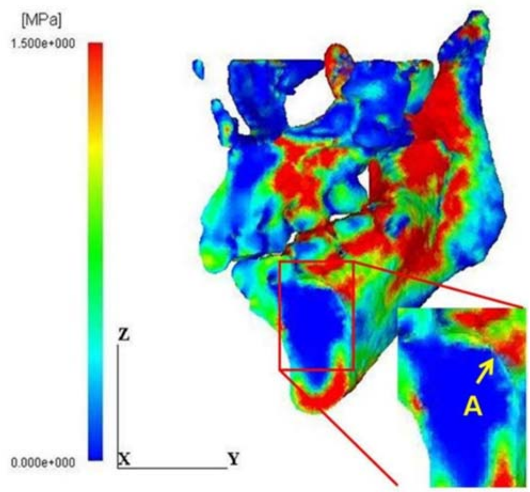
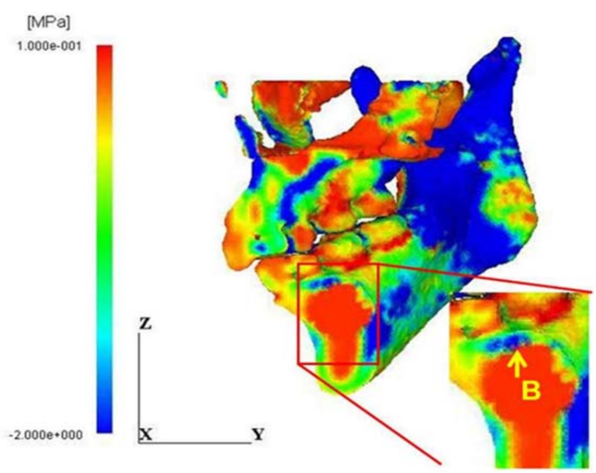


Figure 7: Effect of cyst size on strain energy density.

The maximum and the minimum principal stress distributions are shown in Figure 8. It is noted that the regions A and B of high energy concentration shown in Figure 6(b) correspond to the maximum stress concentration region A in Figure 8(a) and the minimum stress concentration region B in Figure 8(b), respectively. It is thus understood that such energy concentration regions were generated by both high tensile and compressive stress concentration in the vicinity of the cyst. In general, the tensile strength of bone is much lower than the compressive strength; therefore, the initiation of fracture of the mandible with the cyst is likely to take place at the point A.



(a) Maximum principal stress



(b) Minimum principal stress

Figure 8: Distribution patterns of principal stress values.

The mechanical boundary condition used in this study imitated a simple occlusion condition with moderate forces, therefore, the stress level may not be so severe one that causes fracture of the mandible. In order to apply the developed model to the prediction of such fracture problems, more severe mechanical boundary conditions that imitate, for example, falling down and impact of foreign object need to be considered.

4. Conclusions

3D finite element model of a jaw bone with cyst was developed using CT-images. Young's modulus distribution was also considered by using bone density distribution estimated from the CT values. Stress analysis was then performed in order to assess the effect of cyst on the concentrations of strain energy density and principal stress values. The conclusions are summarized as follows:

- A computational jaw bone model consisting of maxilla and mandible was successfully developed using CT-images.
- A distribution pattern of Young's modulus was obtained from the bone density distribution estimated by using CT values.

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