A NOVEL APPROACH FOR MEASUREMENT OF ELASTIC MODULUS OF TRABECULAR BONE IN MANDIBLE

Y. Dohi[1], Y. Othuka[1], M. Inose[2], N. Suda[1] and S. Arikawa[3]

[1] *Division of Orthodontics, Department of Human Development and Fostering Meikai University School of Dentistry*
[2] *Graduate School of Science and Technology, Meiji University*
[3] *Department of Mechanical Engineering Informatics, Meiji University*

e-mail: yosuke.dohi@dent.meikai.ac.jp

1. Introduction

Stress analysis of cortical bone and trabecular bone in the jaws is very important for not only basic science but also accurate diagnosis and effective treatment in clinical dentistry. Currently, finite element method (FEM) is widely used for such stress analysis. FEM is a numerical analysis, that is, the analysis result largely depends on the substituted material properties. However, characteristic of material properties in the mandible with complicated anatomical structure has not been elucidated. Especially, the property of trabecular bone is still unknown and the properties of the femur and vertebra have been used as substitution values. The reason why it is hard to analyze the material property of trabecular bone in the mandible can be ascribed to the difficulty in obtaining specimen from trabecular bone, and also to the mechanical anisotropy of bone.
Therefore, we tried to apply a method of linear rule of mixtures for mesurement of elastic modulus of mandibular trabecular bone. The linear rule of mixtures is known as an effective method for analysing composite materials in the engineering field. This approach is a procedure of calculating the material properties of a whole composite material from a prediction formula based on product of numbers in each volume fraction and material property in a composite material. By applying this method, it is possible to measure the elastic modulus of trabecular bone without extracting only trabecular bone. In this study, we measured the elastic modulus of the trabecular bone of porcine mandible using linear rule of mixtures.

2. Material and method

Cortical bone and trabecular bone were cut out from the center of the 6 months old pig's mandibular ramus in one piece. For the purpose of repeating the compression test using the linear rule of mixtures, the specimen was precisely trimmed in a rectangular shape. Measurement of the elastic modulus was evaluated by displacement analysis in a compression test using a laser displacement meter (Panasonic, HL-G1) with a specimen placed in the precision universal testing machine (SHIMADZU, AG-250kNplus) at the center of the compression jig. In the experiment, first, the end portion of the specimen was cut and removed repeatedly to arbitrarily reduce its shape, and the elastic modulus of the specimen was measured at each cutting. Then, by using the prediction equation of linear rule of mixtures shown below (1), the elastic modulus of the resected bone was calculated by finding the difference between consecutive data. E_f is the modulus of elasticity of the part cut and removed, E_c is the elastic modulus before cutting and removal, E_m is the elastic modulus after cutting and removal, V_m is the volume fraction after cutting removal, and the following equation (1) was obtained by transforming linear rule of mixtures.

(1)
$$E_f = \frac{E_c - V_m E_m}{1 - V_m}.$$

In experiment 1, trabecular bone with cortical bone at both ends of the specimen was used. In experiments 2 and 3, trabecular bone with cortical bone only at one end of the specimen was used, and modulus of such different bones structure were measured. As for the measurement error due to the deformation of the jig of the precision universal testing machine, we calculated the correction value from the basic experiment using the aluminium alloy (JIS A 2017) and corrected the result of experiments 1, 2, and 3.

3. Result

The elastic modulus of Experiment 1 in which specimen was cut three times were 11.9 GPa for bone including cortical bone and 3.8 GPa and 6.2 GPa for bone with only trabecular bone in order from lingual side. The elastic modulus of Experiment 2 in which specimen was cut twice were 1.2 GPa and 1.9 GPa in order from the lingual side. The elastic modulus of experiment 3 in which specimen was cut four times to obtain narrow range data of the trabecular bone were 5.0 GPa, 3.9 GPa, 3.6 GPa and 8.3 GPa in order from the lingual side.

4. Discussion

From the finding of experiment 1, since elastic modulus was low high and low in cortical bone and trabecular bone respectively, it was suggested that linear rule of mixtures was useful to determine the elastic modulus. From experiments 2 and 3, it was found that the elastic modulus of trabecular bone greatly varies depending on the excised site. From all these findings, elastic modulus could be calculated without extracting trabecular bone solely. The modulus was determined at any arbitrary site having cortical and trabecular bones. By utilizing more accurate elastic modulus distribution of bone, it is expected to clarify the correct mechanical properties of trabecular bone.

References

[1] E. Lakatos, L. Magyar and Imre Bojtar. Material Properties of the Mandibular Trabecular Bone. *Journal of Medical Engineering*, 2014;2014:470539, doi:10.1155//2014/470539. Epub 2014 Oct 29. https://www.hindawi.com/journals/jme/2014/470539

[2] M. Sakamoto, K. Sato, K. Kobayashi, J. Sakai, E. Takano and T. Hara. Measurements of Mechanical Properties of Cortical Bone Using Nanoindentation Tests. *Japanese Journal of Clinical Biomechanics*, 24: 1-5, 2003.

[3] J. Takayanagi. Mechanical effect of bite force at different occlusal regions on mandible and temporomandibular joint : Using the three-dimensional finite element method models. *Orthod Waves.Jpn Ed*, 65(1): 11~23, 2006

[4] M. Kohara. A dynamic study of multi-bracket appliance using a digital image correlation method combined with three-dimensional finite element analysis : stress distribution in the root surroundings during maxillary anterior retraction. *Orthod Waves.Jpn Ed* 69(1): 141~155, 2010