MEASUREMENT SYSTEM WITH NANO-RESOLUTION FOR MICROSCOPIC BONE PROPERTY

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INTRODUCTION

To understand physiological and pathological behavior of human skeletal system, the accurate measurement of biomechanical properties for bone is the one of important works. Particularly, the microscopic measurement of human bone is important since the biomechanical behavior at the small scale of bone could be closely related to the remodeling of bone. The remodeling processes of bone have been investigated by using various mechanobiological models [1]. Thus, significant attempts have performed to directly measure the microscopic biomechanical properties of human bone using small scale specimens. They used the three-point or four-point bending, and tensile tests [2-4]. However, the use of coarse microtesting machines and irregular shape of micro-specimens could cause significant measurement errors. For example, the microscopic elastic modulus could vary from 4.59 GPa to 10.4 GPa for the human trabeculae at the same anatomical site depending on the selection of the test method [2-4]. In this study, a small scale compressive testing machine was developed to measure accurate microscopic elastic moduli of bone.

METHODS

Fig. 1 (a) shows a schematic diagram of the small scale compressive testing machine. The testing machine had a PZT actuator (PI Gmbh, Germany) for axial loading. The axial loading PZT actuator could load up to 3000 N with a full displacement range of 120 μm. When a loading displacement was measured with l2-bit A/D converter, the resolution of the testing machine was 30 nm. To check the accuracy of the testing machine, A6061S-T6 aluminum alloy rectangular parallelepiped having the compressive strength of 265 MPa (2 x 2 x 4 mm^3) was manufactured and subjected to the compression test to examine the accuracy of measuring the compressive strength. When aluminum specimens were loaded up to a strain of 0.5 %, the measurement error was about 0.2 %. Thus the measurement system was accurate.

Five bovine cortical bone specimens were used in this study. A micro-milling machine (EGX-300, Roland, Japan) was used to obtain rectangular parallelepiped cortical specimens (300 x 300 x 600 μm^3) from near the spinous process of lumbar vertebra. Fig. 1 (b) shows this specimen. Compressive strain of up to 1% was applied using the PZT actuator at a strain rate of 0.001/sec. The linear regression analysis was performed to represent the stress-strain relationship. The Young's modulus was determined as the slope of the tangential line to the regression curve.

RESULTS

Figure 2 shows the mean stress-strain behavior. The mean Young's modulus of the bovine lumbar vertebral cortical bone measured in this study was 10.3 GPa (SD ± 0.7). Based on the previous studies, the elastic moduli of cortical bone obtained from bovine femur were about 14 GPa in the macroscopic level [5], and 21 GPa at the osteon [6]. Since the microscopic elastic modulus in this study was obtained using bovine lumbar vertebrae, which are weaker than femur, the results would be reasonable.

(a) (b)

Figure 1: Developed measurement system and fabricated microscopic cortical specimen

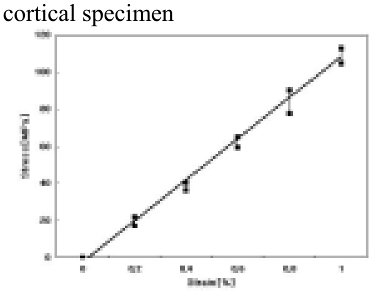

Figure 2: Obtained stress-strain curve with the standard deviation error bar

CONCLUSIONS

In this study, a small scale compressive testing machine was developed to measure accurate microscopic elastic moduli of bone. Experiments were also conducted to validate the accuracy and suitability of the measurement system. The developed system will be useful to understand the biomechanics of the bones at a micro-scale.

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