ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

THREE-DIMENSIONAL DEFORMATION FIELD MEASUREMENT IN CANCELLOUS BONE BASED ON MICRO-CT IMAGING

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INTRODUCTION

Variation of mechanical properties in bone is considered to be very sensitive to micro-deformations throughout interior structure. Although the measurements of deformation are variously introduced by different research purposes, the limitations of each measurement cannot be facilely ignored. Especially in FEA method, the material properties should be assumed artificially which hardly behave as natural tissues.

In this study, we not only developed a direct deformation measurement system which integrated mechanical testing machine and micro-CT, but also presented a method to calculate three-dimensional deformation based on micro-CT images.

METHODS

Specimen preparation

Three cancellous bone samples were harvested from porcine femoral head and processed into cubic shape with 1cm×1cm×1.5cm in size.

Micro-CT scan with cancellous bone compressed

To visualize deformation distribution in cancellous bone, we developed an experimental setup consisted of micro-CT and miniature mechanical tester. The tester could apply stepwise uniaxial compression to the specimen and was designed to fit within the micro-CT apparatus. Both of fixing ends were made of polyoxymethylene that not only performed enough stiffness to resist reaction forces during loading, but also provided a radiolucent region for X-ray penetration during micro-CT scanning.

Each specimen underwent a stepwise compression routine (0N, 100N, 300N). And the 0N testing was performed twice to estimate the accuracy of the deformation testing system. After each step, specimens were imaged with micro-CT (Explore Locus, GE healthcare, USA) in order to track the progression of deformation and identify displacements. The specimen was scanned at 45μm voxel resolution and in result of 400 sequential images for calculation.

Displacement calculation by digital volume correlation

Assuming that CT images have sufficient number of feature patterns, we used the digital volume correlation technique to find displacement vectors at given pixels in a series of images. The displacement field between a reference state and a deformed state of bone structure was measured on a 3D virtual grid. The displacement of each point on this grid was calculated by intercorrelation of the grey levels of the neighbourhood surrounding the considered point in both states. The correlation coefficient C was defined as below equation.

$$C = \frac{N^3 \sum\sum\sum(f * g) - (\sum\sum\sum f) * (\sum\sum\sum g)}{[N^3 \sum\sum\sum f^2 - (\sum\sum\sum f)^2]^{\frac{1}{2}} * [N^3 \sum\sum\sum g^2 - (\sum\sum\sum g)^2]^{\frac{1}{2}}}$$

RESULTS AND DISCUSSION

At 0N loading, the calculated deformations at X, Y, Z direction were 6.615±2.520μm, -3.420±1.710μm and 0.495±3. 240μm respectively. And the accuracy of the whole system at zero displacement was about ±3.535μm. The compression of cubic cancellous bone specimen shown (1) that the structural displacement range of interest on loading axis was 18.90μm ~29.25μm, (2) that value of displacement near movable end was much more than the one near fixing end, (3) that displacement field distribution gradually transformed in multilayer on loading axis but was symmetry on vertical plane. These results indicated that microdeformation of trabecular bone accorded with the characteristics of usual material deformation.

CONCLUSIONS

This paper presents a deformation measurement system which consists of mechanical tester and micro-CT to analyze 3D displacement field distribution in cancellous bone. The results of experimental applications confirm that this system can be used to evaluate displacement field under compression. In future work, we will continually research about the relationship between distribution of deformation and structural factors, meanwhile improve the accuracy and precision of measurement.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (No. 30872633，No.30930092).

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