CALIBRATION OF THE ZETOS BONE LOADING SYSTEM

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INTRODUCTION

An ex vivo bone culture and loading system, ZETOS, has been developed to evaluate morphological and physiological cellular responses of trabecular bone cylinders (10 mm diameter, 5 mm height). A cylindrical piezoelectric actuator (PZA) expands while compressing the specimen. Strain gauges and a load cell measure PZA expansion and applied load, respectively. These, however, are not representative of the specimenôs compressive deformation due to the compliance of the system. Therefore force, expansion and specimen deformation are related by means of a calibration table (Jones et al, 2003; Smith et al, 2001).

Calibration was performed at manufacture, but the compliance of the system may change with time, thus the requirement of recalibration. The purpose of this investigation was to develop and validate a recalibration protocol for the ZETOS bone loading system.

METHODS

Ten aluminum reference bodies (RBs) with a known stiffness were designed and manufactured (Figure 1). The RB stiffness ranged from 40 MPa to 2000 MPa which is a reprehensive range of trabecular bone. The main feature of the RB design was a diaphragm which would deflect under a compressive axial load applied to a central piston. In order to comply with geometric and mechanical limitations, two groups of RB geometries were required, differing in lateral wall thickness and fillet radii. A range of diaphragm thicknesses was determined for each geometry to span the desired range of stiffness.

Calibration of the PZA expansion under no load was performed using a fiberoptic distance sensor. All RBs were tested, ten times each, in ZETOS to record force and PZA expansion.

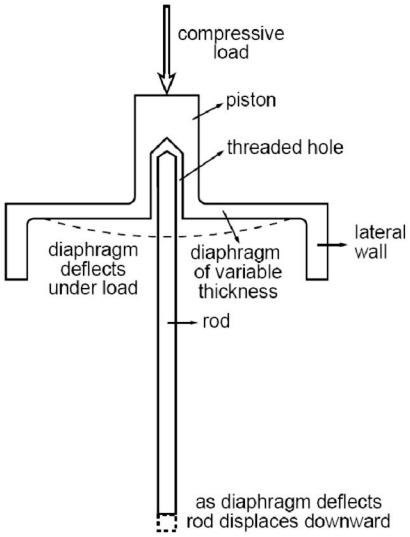

Figure 1: Schematic of a section view of a RB and stainless steel rod.

Finite element analysis (FEA) was used to model compression of the RBs in ZETOS. The model included all interface surfaces: a steel base (ZETOS loading platform), the RB, a sapphire cylinder (10 mm diameter, 10 mm height, used to avoid RB indenting) and the convex, sapphire crystal on the

loading end of the PZA. A displacement of 60 μm was assigned to the top of the PZA crystal. The reaction force was divided by deformation to find RB stiffness, which was found at the top of the surface and at the threaded cavity.

The reference body (RB) stiffness determined with FEA was validated with physical testing in an Instron device. Six RBs were compressed using a setup replicating the FE model. Compressive deformation of the RBs was derived from measurements with a 10x microscope. Percent differences of the FEA-determined stiffness were calculated with respect to stiffness found with Instron testing.

ZETOS force and expansion, and compression derived from FEA were related by generating a calibration table through spline interpolation. All the RBs were tested in random order in ZETOS, ten times each. For further verification, three metal specimens of unknown stiffness were also tested in ZETOS and compared to FEA. Comparisons of these tests with respect to FEA were made with percent differences.

RESULTS

Two sites were analyzed in the FEA: at the top of the RB piston and at the threaded cavity. The first was the stiffness of interest, used for calibration; the second analysis site was for comparison with experimental testing aimed to validate the model.

FEA results had a mean percent difference (absolute value) with respect to Instron testing of 5.08%, ranging from -3.21 to 10.6%. This comparison used the stiffness calculated at the threaded cavity in the FEA to mimic the displacement measurements taken during physical testing. Results from Instron testing served as FEA validation.

A calibration table was generated, based on the displacement results found at the top of the piston from the FEA. Verification of the RB stiffness determined using the ZETOS loading system after calibration found a mean percent difference (absolute value) of 1.10%, ranging from -2.07 to 0.877%. Finally, the verification of the calibration procedure using metal springs found a mean percent difference in stiffness compared with their FE models of 2.25%, ranging from -3.31 to 2.78%.

DISCUSSION AND CONCLUSIONS

The calibration procedure of the ZETOS loading system is important to assure accuracy of stiffness measurements of trabecular bone. FEA was an essential tool in this study, both for design of the RBs and for calculation of their stiffness. The combination of experimental testing and FEA enabled a more precise determination of RB stiffness for the generation of the calibration table. The test results were used to validate the FEA; and subsequently, the FEA provided results that could not otherwise be measured to generate the calibration table. The successful calibration of the ZETOS loading system assures continuing accuracy of stiffness measurements of trabecular bone.

REFERENCES

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