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Research paper

Direct comparison of nanoindentation and macroscopic measurements of bone viscoelasticity

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ABSTRACT

Nanoindentation has become a standard method for measuring mechanical properties of bone, especially within microstructural units such as individual osteons or trabeculae. The use of nanoindentation to measure elastic properties has been thoroughly studied and validated. However, it is also possible to assess time dependent properties of bone by nanoindentation. The goal of this study was to compare time dependent mechanical properties of bone measured at the macroscopic level with those measured by nanoindentation. Twelve samples were prepared from the posterior distal femoral cortex of young cows. Initially, dogbone samples were prepared and subjected to torsional stress relaxation in a saline bath at 37 °C. A 5 mm thick disk was subsequently sectioned from the gage length, and subjected to nanoindentation. Nanoindentation was performed on hydrated samples using a standard protocol with 20 indents performed in 20 different osteons in each sample. Creep and stress relaxation data were fit to a Burgers four parameter rheological model, a five parameter generalized Maxwell model, and a three parameter standard linear solid. For Burgers viscoelastic model, the time constants measured by nanoindentation and torsion were weakly negatively correlated, while for the other two models the time constants were uncorrelated. The results support the notion that the viscoelastic behavior of bone at the macroscopic scale is primarily due to microstructural features, interfaces, or fluid flow, rather than viscous behavior of the bone tissue. As viscoelasticity affects the fatigue behavior of materials, the microscale properties may provide a measure of bone quality associated with initial damage formation.

1. Introduction

Nanoindentation provides a means to assess the mechanical properties of bone at very small length scales (Gupta et al., 2005; Rho et al., 1997; Turner et al., 1999; Zysset et al., 1999). In the case of cortical bone, nanoindentation can be used to measure mechanical behavior at the level of individual osteons (Huja et al., 2006; Rho et al., 2001) or even lamellae (Rho et al., 1999a,b). It is one of the few methods capable of directly assessing mechanical behavior of the bone tissue within individual trabeculae (Rho et al., 1997; Turner et al., 1999; Zysset et al., 1999). A nanoindentation instrument measures the load and deformation of a probe as it is advanced into the surface of an object. The data are typically used to estimate the elastic modulus, which is calculated by the Pharr–Oliver equations (Oliver and Pharr,

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