TRANSVERSE DAMAGE AND FAILURE BEHAVIOR OF TRABECULAR BONE

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INTRODUCTION

Osteoporosis is a disease involving trabecular bone that affects many elderly people and is a growing health problem. Many patients are confined to a nursing home for six months or more after treatment of an osteoporotic fracture. Most fractures occur during falls and at anatomic sites where trabecular bone is the major load-bearing element. Therefore, trabecular bone strength during off-axis loading is important for understanding the mechanisms of clinical hip fractures. This information will help identify patients at risk of fracture and develop treatments.

Microdamage is present *in vivo* in trabecular bone in humans, but its role in bone failure is not clear. Recent studies in cortical bone found that higher levels of microdamage were consistent with increased fatigue life. Microdamage has been shown to decrease the modulus of trabecular bone samples loaded along the principal elastic direction. However, the damage behavior for loading along other mechanical axes has not been characterized.

Trabecular bone could be damaged during falls or other off-axis loads, leading to diminished mechanical properties and increased fracture risk. The goal of this research was to determine how microdamage affects the failure behavior of trabecular bone under off-axis compressive loading. Specifically, 1) microdamage was induced to two different levels and 2) changes in the modulus failure properties were quantified.

Ten bovine tibial trabecular bone samples were prepared from eight tibiae. Five samples were randomly assigned to either the low or high damage group. Cylindrical samples, approximately 8 mm in diameter and 30 mm long were prepared with the stiffest principal elastic direction perpendicular to the cylindrical axis. The samples were embedded in brass endcaps for testing.

The initial elastic modulus of the samples was measured by loading to 0.5% compressive strain. The modulus was taken as the slope of a quadratic curve fit at 0 stress, and was averaged from three load cycles. Samples were then damaged by loading to either 1.5% (low) or 2.5% strain (high). Following the damaging load, the modulus was measured a second time. All specimens were then loaded to 10% strain and the ultimate stress and strain were measured (Fig. 1). To compare between samples, the ultimate stress was divided by the initial modulus.

RESULTS

On average, the orientation of the principal elastic direction was 84 ± 06° from the cylinder axis.

The elastic modulus decreased following the damaging loads. The initial elastic modulus for the samples was 411 ± 234 MPa. The damaged modulus for the low damage group decreased by 21 ± 9.7% in comparison to the high damage group which decreased by 43 ± 29% ($p > 0.17$, Student's t-test, Fig. 1).

Neither the ultimate stress nor strain (Fig. 2) was significantly different between the two damage groups, after compensating for dependence on modulus.

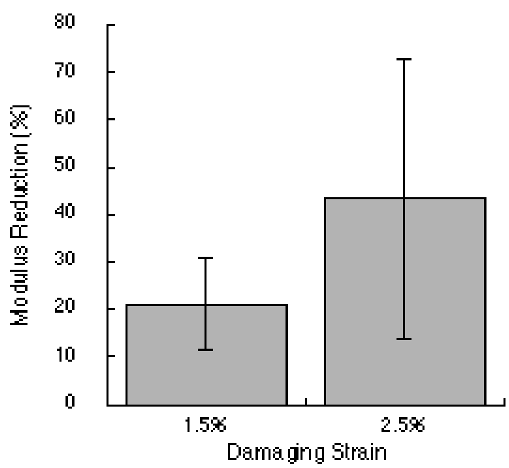

Figure 1: The elastic modulus decreased by similar percentages for samples strained to 1.5% strain and 2.5 % strain ($p > 0.17$). Error bars are one standard deviation (N=5).

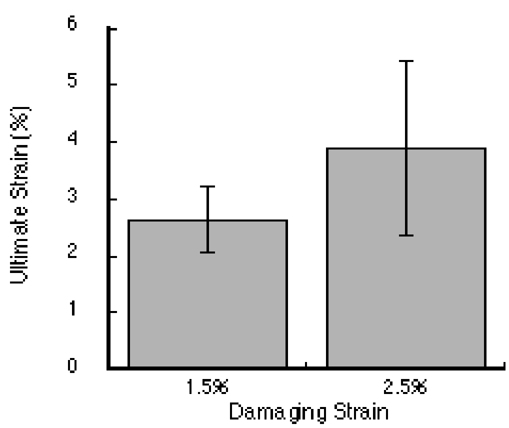

Figure 2: The ultimate strain on the final loading did not differ between the two groups ($p > 0.12$). Error bars are one standard deviation (N=5).

DISCUSSION

The transverse damage behavior of trabecular bone was studied for ten samples loaded to two different damaging strains. Damage to the samples occurred in both cases, with significant modulus reductions for both groups. However, the sample sizes were too small to identify differences in the damage levels between groups. The ultimate properties were also similar between the two groups. As such, this data would suggest that increased levels of damage are not detrimental to the overall failure properties of trabecular bone. However, the number of specimens tested was small, resulting in weak statistical comparisons.

REFERENCES

Braithwaite, RS*, et al.* (2003). *J Am Geriatr Soc* **51**(3): 364-70.

Keaveny, TM*, et al.* (1994). *J Biomech* **27**(11): 1309-1318.

Mori, S*, et al.* (1997). *Bone* **21**(6): 521-6.

Parkkari, j*, et al.* (1999). *Calcified Tissue International* **65**: 183-187.

Sobelman, OS*, et al.* (2004). *J Biomech* **37**(9): 1295-1303.

Wang, X*, et al.* (2004). *J Biomech Eng* **126**(1): 122-125.

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