INVESTIGATION OF THE OBJECTIVES OF ADAPTATION OF A CORTICAL TENSION/COMPRESSION SYSTEM THROUGH MECHANICAL TESTING

Dayton M.R., Skedros J.G., Bloebaum R.D., Bachus K.N.
Bone and Joint Research Laboratory, VA Medical Center and Division of Orthopedic Surgery,
University of Utah School of Medicine, Salt Lake City, UT 84148.

Relevance to Musculoskeletal Conditions It is known that mechanical signals play a role in bone adaptation, maintenance and repair. This study attempts to identify the influences that known remodeling and adaptive changes have on mechanical properties of cortical bone.

INTRODUCTION Assertions that bone adaptation is driven by the objective of establishing uniform safety factors (ratio of bone failure stress to maximum in vivo stress) in the equine radius(1) have recently been disputed through testing in the equine third metacarpal (2). The objective of the present study is to further examine the structure function relationship of a limb bone for which the material and microstructure, as well as morphology have been previously characterized (3). We hypothesize that mechanical property differences in this bone between discrete cortical regions will exist which correspond to strain mode related structural and material variations.

METHODS The artiodactyl (Mule deer) calcaneus is a simply loaded physiologic tension/compression system, thus making it an ideal model for mechanical analysis. Physiologic strain distribution of the Rocky Mountain mule deer calcaneus is characterized by a balanced areal distribution between the plantar (Caudal) region in tension, and dorsal (Cranial) region in compression. One calcaneus was obtained from each of sixteen skeletally mature animals 12-72 hours after death for mechanical tension and compression tests. Specimens were cleaned of soft tissue and stored in moist saline soaked towels at -20C. One 3.0mm diameter x 5.0mm height cylindrical specimen was milled under irrigation from each of the Cranial and Caudal cortices of eight calcanei at 60% length, producing a total of 16 specimens for compression tests. From the remaining eight calcanei, one cortical tensile specimen was milled from each of the Cranial and Caudal cortices (1).

Mechanical compression and tensile tests to failure along the longitudinal diaphyseal axis of each specimen were performed using an Instron 1125 at a strain rate of 0.005/sec (4). All testing was conducted using a 5 kN load cell. For compression tests, corrected crosshead displacement was used for strain data. Specimens were aligned in grips for tension tests, and an MTS extensometer was used for displacement readings. Young's modulus (stiffness) and ultimate stress (strength) were calculated. Statistically significant differences were noted using ANOVA analysis with Fisher's post-hoc paired comparisons.

RESULTS Marked differences in stiffness and strength were noted between Cranial and Caudal regions ($p<0.0001$) in compression tests (Table 1). Variations between regions were minor in tension tests for both stiffness ($p=0.821$) and strength ($p=0.546$), with an observed 4% higher tensile strength in the Cranial region over the Caudal region. Significant differences also existed between each of the two cortical regions in tension testing and the Cranial region in compression testing ($p<0.0001$) for both mechanical parameters.

DISCUSSION Past observed regional differences in mineral content and microstructure in the calcaneus model, if representative of meaningful mechanical adaptation, should be reflected as variation in mechanical behavior between regions. The mechanical parameter differences indicated by the above data exist across the cortex at the approximate midshaft (60%) of the artiodactyl calcaneus, a length where the greatest regional physiologic strain related differences in structural and material properties have been observed (3). Comparisons of stiffness and strength values of the Caudal region in tension, to the Cranial region in compression are important because this is most representative of conditions of the prevailing in vivo loading environment (3).

Past calcaneus strain characterization suggests that the Cranial cortex primarily experiences physiologic compressive strains, peak magnitudes of which are roughly 50% higher than the maximum predominant tensile strains experienced in the Caudal cortex (4). The relatively low compression strength observed here in the Caudal cortex may be attributed to a stress-reducing effect of the adherent plantar ligament, reducing customary in vivo strains in this cortex, thus raising the possibility that this region habitually exists in a state of relative disuse.

This data suggests that strains produced during customary physiological loading, with possible corresponding cortical bending, convey some biologically useful information which contributes to maintaining bone mechanical competence and morphology (5). Consequently, apparent strain related regional differences in structural and material adaptation described in the Mule deer calcaneus(3) as well as other limb bones(1,6) appear to alter stiffness and strength behavior, as supported by this data. This may serve to maintain optimal bone organ homeostasis, while concurrently maintaining cortical structural integrity through establishing adequate, but not necessarily uniform safety factors.

Figure 1

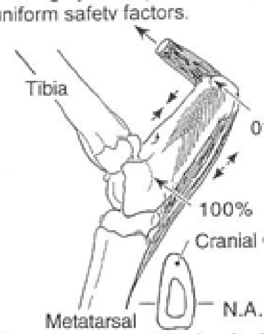

Table 1. Mule Deer Calcaneus Mechanical Data*

Test Mode	Cortical Region	Young's [GPa]	Ultimate Stress [MPa]
Tension	Cranial [n=4]	10.35 (0.39)	134.56 (4.87)
	Caudal [n=6]	10.09 (0.95)	129.54 (10.49)
Compression	Cranial [n=8]	15.08** (2.11)	199.41** (12.36)
	Caudal [n=7]	8.43 (2.24)	138.09 (16.72)

*()=Std. Dev. **p<0.0001

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FULL Name, Address, Phone, Fax, and E-Mail Numbers of Corresponding Author:
Michael R. Dayton
Bone & Joint Research Lab (151F)
VA Medical Center
500 Foothill Blvd.
Salt Lake City, UT 84148
Tel: (801) 582-1565 Ext. 4607
Fax: (801) 584-2533