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THE IMPLICATIONS OF REDUCED GROUND REACTION FORCES DURING SPACE FLIGHT FOR BONE STRAINS

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INTRODUCTION

The specific mechanisms regulating bone mass are not known, but most investigators agree that bone maintenance is largely dependent upon mechanical demand and the resultant local bone strains. During space flight, bone loss such as that reported by LeBlanc et al. (1996) may result from failure to effectively load the skeleton and generate sufficient localized bone strains.

In microgravity, a gravity replacement system can be used to tether an exercising subject to a treadmill (Davis et al. 1993, McCrory 1997). It follows that the ability to prevent bone loss is critically dependent upon the external ground reaction forces (GRFs) and skeletal loads imparted by the tethering system. To our knowledge, the loads during orbital flight have been measured only once (on STS 81). Based on these data and data from ground based experiments, it appears likely that interventions designed to prevent bone loss in micro-gravity generate GRFs substantially less than body weight. It is unknown to what degree reductions in external GRFs will affect internal bone strain and thus the bone maintenance response.

To better predict the efficacy of treadmill exercise in micro-gravity we used a unique cadaver model to measure localized bone strains under conditions representative of those that might be produced by a gravity replacement system in space.

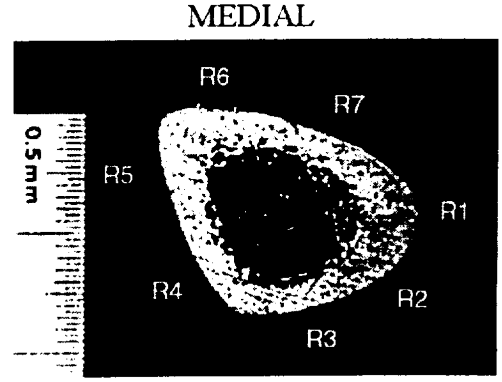
METHODS

Cadaver limbs were mounted into a dynamic loading apparatus that reproduces the kinetics and kinematics of the tibia, foot, and ankle during the stance phase of gait (Sharkey and Hamel, 1998). The device is able to produce GRFs equivalent to those produced in life. Physiologic muscle actions are simulated using force feedback controlled linear actuators interfaced with the tendons of the specimen using freeze clamps.

The distal third of the tibiae were each instrumented with seven miniature strain gauge rosettes (Micro-Measurements Group, Inc. EA-06-031RB-120) oriented on a transversely co-planar section (Figure 1). Dynamic gait simulations were conducted at GRFs corresponding to 25%, 50%, 75%, and 100% of body weight (BW). Strain data were collected over the entire stance phase

MEDIAL

POSTERIOR



ANTERIOR

LATERAL

Figure 1. Tibial cross-section showing strain gauge placement.

and the results were used as input for a computer model of bone strains over the stance phase.

RESULTS

Decreased GRFs produced proportional decrements in peak tibial strains (Figure 2). At all gauge locations, development of maximum strains within the specimen corresponded to the second peak of the GRF profile. The overall strain maxima for each condition was compressive and occurred along the posterio-medial border of the tibial cross section. Maximum tensile strains occurred anteriorly on the tibial crest. Animations of the strain profiles from heel-strike to toe-off were created using SIMM and MATLAB and will be presented.

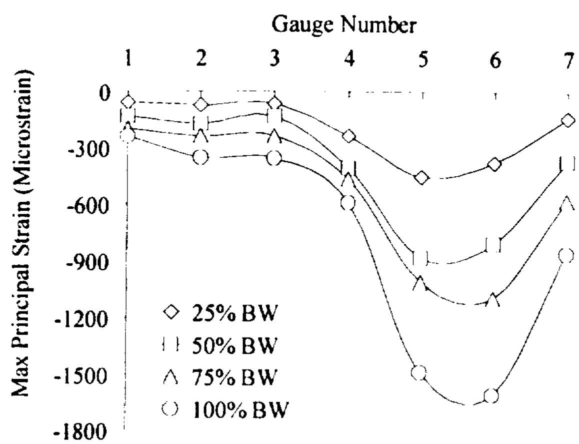


Figure 2. Peak maximum principal strains on the tibia for varying GRFs during simulated walking.

DISCUSSSION

Several investigators have attempted to measure *in vivo* strains in the human tibia, but these studies have been somewhat limited (Lanyon et al., 1975; Milgrom et al., 1996; Burr et al., 1996; Aamodt et al., 1997). *In vivo* human studies have focused on the antero-medial aspect of the tibia due to ethical concerns and technical constraints. Using a robust cadaver model we found that peak strains occur at sites other than those typically measured in live human subjects.

The strain distributions measured in the current study indicate bending as the primary mode of tibial loading and muscle force (i.e. the triceps surae) as the principal modulator of bone strain. Carter et al. (1987) and Turner (1998) have derived separate theoretical equations of bone adaptation based, among other things, on the magnitude of stress or strain experienced by the bone. Our data suggest that *in-situ* bone strains can be reliably related to the external loading environment, so that these equations can be used to calculate a theoretical stimulus using GRFs as input.

CONCLUSION

Internal tibial strains can be predicted using external GRFs. This inter-relationship is important for understanding the bone stimulating potential of various exercise interventions during space flight.

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