INTRODUCTION

Individuals who accumulate greater bone mass early in life may delay the onset of osteoporosis and associated fractures because they have more bone to lose later in life (Friedlander et al., 1995). It is known that the skeleton responds to increased mechanical usage by depositing more bone mass. During years of rapid growth (adolescence) habitual participation in activities that increase skeletal loading may build additional bone mass and help prevent osteoporosis and fractures in old age.

The daily stress stimulus theory proposes that bone remodeling and homeostasis can be predicted by multiplying the number of loading cycles \( n \) incurred at particular stress magnitudes by those magnitudes \( \sigma \) raised to an exponent \( m \), and then summing over the entire range of stress magnitudes encountered in a day (Carter et al., 1997).

\[
\Psi = \left[ \sum_{\text{day}} n_i \sigma_i^m \right]^{1/m}
\]

Whalen et al. (1988) substituted an external measure of ground reaction force (GRF) for the effective stress term \( \sigma \) and proposed that the daily stress stimulus could be effectively estimated from GRF history. Unfortunately, accurate and continuous measurement of GRF is technically difficult. Accurate GRF measurements require stationary ground-based force platforms. Portable in-shoe systems have been developed but these devices tend to have low frequency responses and yield inconsistent results. Portable and continuous measurement of acceleration may be a more practical approach in humans because accelerometers have a high frequency response and are small and relatively unobtrusive. The goal of this study was to determine if accelerations measured at the distal tibia correlate with GRFs, in the hope that they might provide a useful index of skeletal loading.

PROCEDURES

Vertical ground reaction forces, and accelerations of the distal tibia were measured using a force platform (Kistler Model 9287A) and a uniaxial accelerometer (Kistler Model 802BD) respectively. A custom holder and Velcro\textsuperscript{TM} strap, secured as tightly as possible without causing discomfort, were used to mount the accelerometer just proximal to the ankle, with its axis aligned with the long axis of the tibia. Ten healthy female subjects between the ages of 17 and 30 were tested while performing the following activities: walking, running, cutting at a 45-degree angle while running, and jumping down from heights of 20cm (8”), 40cm (16”), and 60cm (24”). All subjects wore athletic shoes. Each subject executed three trials of each activity while GRFs and accelerations were recorded at 1000 Hz using a portable PC, a National Instruments PCMCIA data acquisition card, and LABVIEW software.

All forces were normalized to body weight and data were compiled for all activities. Regression analyses were then performed to
determine the relationships between distal tibial acceleration and peak vertical ground reaction force, initial vertical loading rate (slope to first peak of the vertical GRF profile), and initial impulse (area under the first peak).

**RESULTS**

Average tibial accelerations ranged from 2.9g for walking to 48.2g for jumping from a 60cm (24") height (Fig. 1). Within-subject accelerations were consistent for each activity but varied considerably across subjects. For example, tibial accelerations for jumping from a 40cm (16") height was subject dependent and ranged from 11.0g to 53.3g.

**DISCUSSION**

We found that accelerations at the distal tibia during walking, running, cutting, and jumping were significantly correlated to both the initial peak in vertical GRF (normalized to body weight) and the initial vertical loading rate. Though these relationships were highly significant (p < 0.001) they indicate that tibial accelerations can only explain about one-half of the variance in ground reaction forces. This finding is not surprising given that GRFs are dependent on the accelerations and mass of the whole body, whereas our acceleration measurements consider some unknown fraction of that mass. Clearly, other factors, such as body mass distribution, footwear, and motor coordination also influence the accelerations measured at the distal tibia.

**CONCLUSION**

Our data suggest that monitoring tibial accelerations may be useful for tracking skeletal loading but it is by no means ideal. Further research and development of other more predictive technologies appears to be warranted.

**REFERENCES**

