

LONG BONES OF THE LOWER EXTREMITY EXPERIENCE SIMILAR STRAIN PROFILES DURING GAIT

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INTRODUCTION

The primary mode of loading in most long bones is bending, with some superimposed axial compression. This bending and the resulting strains have been shown to be enhanced by the inherent curvature of long bones (Bertram and Biewener, 1988). It is also thought that bone curvature may serve to increase loading predictability and to achieve repeatable strain patterns during gait.

In addition to bone curvature, functional strains are influenced by other 'loading factors' that may include, but are not limited to, cross sectional geometry, tissue heterogeneity, and applied forces (muscle force, joint reaction force, ground reaction force (GRF)). The exact contribution of each of these factors will necessarily vary from one bone to the next.

The aim of this study was to determine if the different combination of loading factors acting on separate bones could conspire to produce similar strain distributions during functional loading. The study utilized a dynamic gait simulator (DGS) to characterize the strain distribution in the tibia and first metatarsal during the stance phase of gait. These bones were chosen because of their distinctly different structure and orientation within the lower extremity. Additionally, metatarsal curvature actually resists rather than enhances the naturally occurring bending moments due to the GRF.

METHODS

The DGS reproduces the kinematics and kinetics of the stance phase of gait (Sharkey and Hamel, 1998) while simulating the physiologic actions of the major extrinsic muscles of the foot. Five cadaver limbs were instrumented with strain gages, mounted in the DGS, and subjected to five trials under normal gait conditions.

The distal third of each tibia was instrumented with four stacked rosette strain gages (Micro-Measurements Group, Inc. WA-06-060WR-120) located on the anterior, medial, posterior, and lateral aspects of the bone within the same transverse plane. Rosettes were also affixed in the same manner to the dorsal, lateral, and plantar aspects of the mid-diaphysis of the first metatarsal. Strain data were collected simultaneously from both bones for the duration of each trial.

Principal strains and directions were calculated at each gage site. Axial strain gradients were calculated across the transverse section using the method of Rybicki et al. (1977).

RESULTS

The strain profiles of the two bones followed the magnitude of the vertical GRF (Figure 1). The tibia appears to be more affected by forces at heel strike than the metatarsal. However, both bones reach peak

strains at toe-off. The magnitude of strains developed at the periosteal surface of the tibia was always greater than the first metatarsal strains. Throughout mid-stance, the average variation in principal axis direction was $9 (\pm 3)$ degrees in the tibia and $32 (\pm 18)$ degrees in the metatarsal.

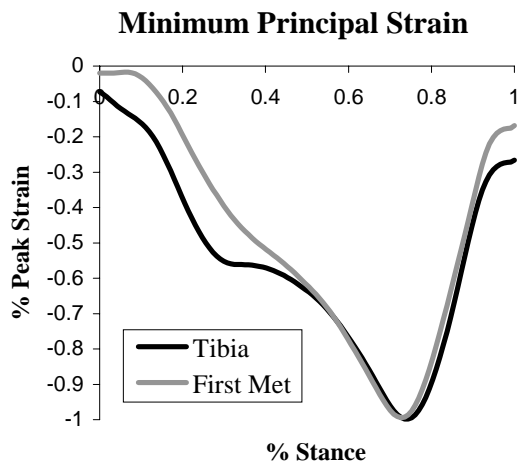


Figure 1: Normalized minimum principal strains of the posterior tibia and dorsal surface of the first metatarsal during stance. The plots represent average strains at each location over all five specimens.

DISCUSSION

Based on the structure and orientation of each bone, it is not necessarily intuitive that they would experience similar strain profiles during gait. Both the intrinsic (curvature, cross section geometry) and extrinsic loading factors in each bone resulted in a restricted strain environment that was consistent between the two bones and across specimens.

Of particular interest was the relationship between the direction of bone curvature and whether this curvature tended to resist or enhance bending of the bone. Bertram and Biewener have proposed that bone curvature serves to increase the loading predictability

of bone while accentuating bending strains (1988). The first metatarsal is an exception to this case in that both the direction of curvature and the applied muscle forces act to *reduce* bending moments caused by the GRF.

It seems plausible therefore that the role of bone curvature is not necessarily to enhance bending strain, but is more suited to simply increase load predictability and provide a means to achieve a repeatable strain distribution. Strain magnitudes are then modulated by other extrinsic factors such as applied muscle forces and GRF. Loading predictability would appear to be especially critical in the metatarsals, where more variable external loading regimes occur, and curvature can serve to redirect variable forces into a repeatable loading pattern.

SUMMARY

Similar patterns of functional strain occur in the tibia and first metatarsal during normal gait even though different loading factors act on each bone. This finding suggests that strain profiles are not unique to a single bone, and loading predictability is important regardless of the tendency of bone curvature to either enhance or restrict bending strains.

REFERENCES

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