

# INTERNAL FEMORAL FORCES AND MOMENTS DURING RUNNING: IMPLICATIONS FOR STRESS FRACTURE DEVELOPMENT

W. Brent Edwards<sup>1</sup>, Jason C. Gillette<sup>1</sup> Joshua M. Thomas<sup>2</sup>, and Timothy R. Derrick<sup>1</sup>

<sup>1</sup> Department of Kinesiology, Iowa State University, Ames, IA, USA

<sup>2</sup> Human Performance and Wellness Department, Trinity International University, Deerfield, IL, USA

E-mail: [edwards9@iastate.edu](mailto:edwards9@iastate.edu) Web: [www.kin.hs.iastate.edu](http://www.kin.hs.iastate.edu)

## INTRODUCTION

Femoral stress fractures are among the most serious of overuse injuries. Certain femoral stress fractures have a tendency to displace and require surgical fixation (Visuri et al., 1988). Bone damage resulting from the fracture itself, as well as perioperative trauma can lead to avascular necrosis, osteoarthritis, and in some instances permanent handicap (Visuri et al., 1988).

In long-distance runners and military recruits femoral stress fractures commonly occur at the neck, medial proximal-shaft, and distal-shaft (Hershman et al., 1990; McBryde, 1985; Niva et al., 2005). The purpose of this study was to determine if the internal femoral forces and moments during running are associated with common sites of femoral stress fractures.

## METHODS

Ten experienced male runners were recruited for this study (age  $22.2 \pm 3.2$  yrs, height  $1.8 \pm 0.1$  m, mass  $69.8 \pm 6.5$  kg). Motion-capture (120 Hz) and force platform data (1200 Hz) were collected while subjects ran at their preferred running speed ( $4.4 \pm 0.5$  m/s). Kinematics of the thigh, leg, and foot were calculated and inverse dynamics were used to obtain joint reaction forces and joint moments at the hip, knee, and ankle.

Kinematic data were imported into a scaled SIMM 4.0 model to obtain maximal

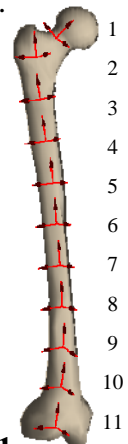
dynamic muscle forces, muscle moment arms, and muscle orientations at each 1% of stance. Static optimization was used to calculate individual muscle forces. The cost function to be minimized was the sum of squared muscle stresses. The optimization was constrained so that the resulting hip, knee, and ankle moments (hip flex/ext, abd/add, introt/extrot; knee flex/ext; ankle flex/ext) equaled experimental data.

Joint contact forces at the hip and knee were calculated as the sum of reaction force and muscle forces crossing the joint. Patella-femoral contact force was calculated as the resultant of the quadriceps and patella ligament forces. Internal femoral forces and moments were calculated at 11 equidistant points along a centroid path in accordance with Duda et al. (1997). Point 1 corresponded to the femoral neck and point

11 corresponded to the femoral condyle (Figure 1). The peak internal femoral loads were calculated and averaged across subjects.

## RESULTS

The mean peak loads were as follows: anterior-posterior (AP) shear,  $-7.47$  BW at point 11 (posterior); axial force,  $-11.40$  BW at point 11 (compression); medial-lateral (ML) shear,  $-3.75$  BW at point 1 (medial);



**Figure 1.** Reference frames for femur points

AP moment, -0.42 BWm at point 2 (medial-surface compression); torsional moment, -0.20 BWm at point 11 (external rotation); ML moment, -0.44 BWm at point 11 (anterior-surface compression) (Figure 2).

## DISCUSSION

Our results suggest that frequently cited locations of femoral stress fracture can be explained biomechanically. The femoral neck is subjected to large ML shear forces. Although, axial forces and bending moments at the neck were not larger than those experienced by the rest of the femur, peak magnitudes occurred during the impact phase and were associated with a high rate of loading. The largest bending moments about the AP axis were observed at the proximal femur. The direction of this moment, combined with the axial compressive force would place the largest normal stress on the medial proximal-shaft. The largest AP shear forces, compressive axial forces, ML bending moments, and torsional moments were observed at the

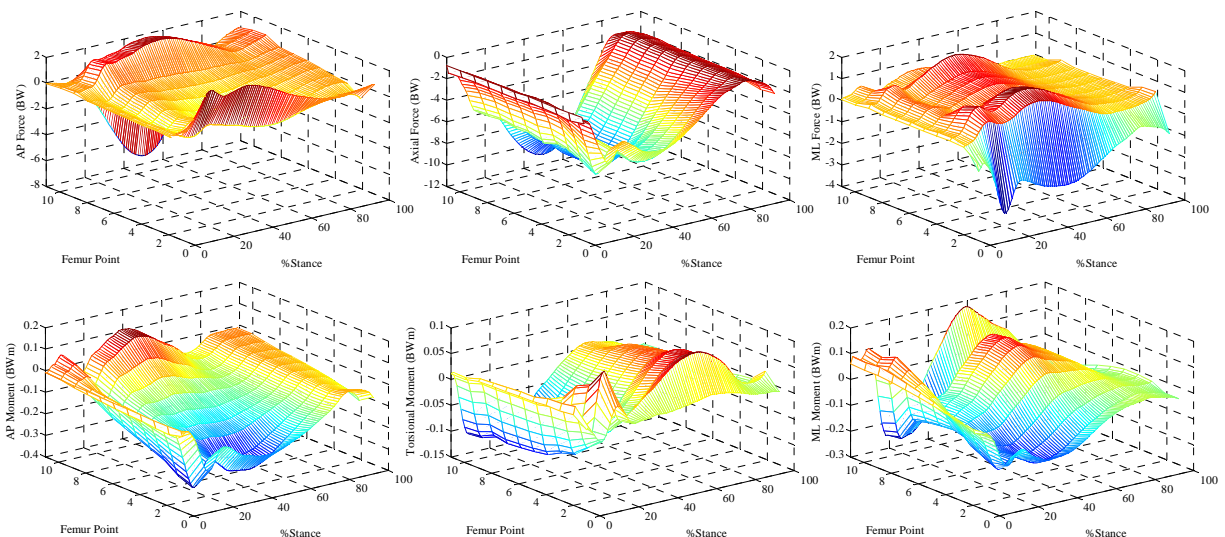
distal-shaft. Overtime, these types of combined loads may pose a threat to skeletal integrity at these three locations.

## SUMMARY

The mechanical loading environment of the femur appears to explain well the locations of femur stress fracture cited in the literature. As each of the three locations experience a relatively unique loading environment, several different mechanisms may be responsible for the development of femoral stress fracture.

## REFERENCES

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**Figure 2.** Group ensemble internal forces and moments at the femur. Positive internal forces correspond to anterior shear, tension, and lateral shear. Positive internal moments correspond to lateral-surface compression, internal-rotation torsion, and posterior-surface compression.