BONE STRAINS ASSOCIATED WITH FEMORAL NECK FRACTURE FOLLOWING HIP RESURFACING

Jason P. Long[1], Thomas J. Santner[2], and Donald L. Bartel[1]

[1]Cornell University, Ithaca, NY; [2]Ohio State University, Columbus, OH
E-mail: jpl38@cornell.edu

INTRODUCTION

The primary mode of short-term failure for hip resurfacing systems is femoral neck fracture (Shimmin, 2005). While some of these fractures are associated with neck notching, or cutting into the neck with an external reamer, others occur in the absence of intrasurgical notching (Anglin, 2007). In such cases, large magnitude bone strains near the implant rim may lead to a region of damage accumulation and eventual short-term fatigue fracture of the femoral neck.

The structural performance of hip resurfacing systems is a function of design (stem loading and implant fixation) and environmental (bone structure, bone stiffness, and joint loading) variables (Chang, 1999). The combination of these variables differs from individual to individual and within the same individual over time. While analysis of a large number of design and environmental variables has traditionally been computationally expensive using the finite element (FE) method, an inexpensive stochastic predictor can improve efficiency (Santner, 2003).

To better understand short-term neck fracture, we used FE analyses in conjunction with an inexpensive predictor function to: 1) determine design and environmental variables that cause an increase in strain magnitude near the implant rim following resurfacing, 2) identify variables that lead to large bone strain magnitudes near the implant rim.

METHODS

Finite element models of the proximal femur were created from computed tomography (CT) scans for intact (pre-op) and resurfaced (immediate post-op) cases. The bone-implant system consisted of the surgically-altered bone, cement mantle, and implant. Bone material properties were assigned element by element using relationships between CT number, apparent density, and elastic modulus (Rho, 1993). Head and abductor loads applied to the models were based upon telemetric implant and gait data (Bergmann, 1993 & 2001). The structural response of the FE models was analyzed as a function of design (stem-hole geometry, shell fixation, and stem friction coefficient) and environmental (bone, bone material stiffness, head load direction, head load magnitude, and abductor load magnitude) variables.

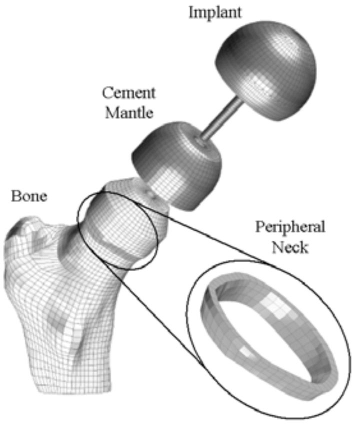

Figure 1: An exploded view of a resurfaced finite element model showing the peripheral neck near the implant rim.

From the FE models, max. and min. principal strains were calculated within the peripheral bone near the implant rim (see Fig 1). The FE models were analyzed at a total of 110 "training sites" throughout the design and environmental variable space to generate the stochastic predictor functions. The predictor functions were then used to analyze the effect of 2000 combinations of the design and environmental variables on strains in the intact and resurfaced models. Sensitivity analysis was done to identify the variables that lead to large magnitude bone strains.

RESULTS

The min. principal strains in the peripheral neck were substantially higher in magnitude and had more variance than the max. principal strains. Additionally, the min. principal strains increased in magnitude by approximately 25% after resurfacing, but only when the implant shell was bonded to the cement mantle (see Fig 2). In some cases, the min. principal strain exceeded 0.35% in magnitude after resurfacing, while the max. principal strains never exceeded 0.15% strain.

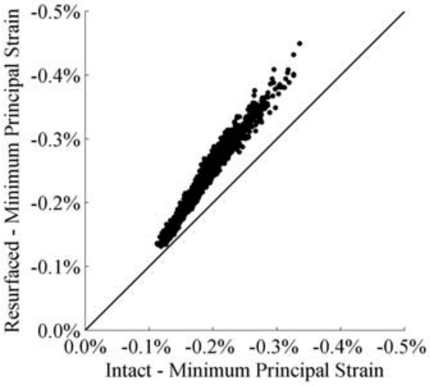

Figure 2: Predicted strains above the bisecting line indicate an increase in strain magnitude after resurfacing.

Bone material stiffness and head load magnitude contributed the most to the variance in min. principal strain, explaining 67% and 23% of the variation, respectively. The highest magnitude strains were primarily associated with low bone material stiffness and high head load magnitude.

DISCUSSION

Resurfacing increased the min. principal strains within the femoral neck near the implant rim by approximately 25% compared to the intact bones. Low bone material stiffness and high head load magnitude were the primary variables that contributed to large magnitude strains. In some cases the min. principal strains exceeded 0.35% in magnitude, indicating a possibility of damage accumulation in the femoral neck due to fatigue loading (Moore and Gibson, 2003). Short-term neck fracture after hip resurfacing may be associated with bone damage accumulation, which is a failure mechanism similar to stress fractures suffered by competitive athletes and military recruits (Burr, 1997).

REFERENCES

Anglin C et al. (2007). *CORR*, 465: 71-79
Bergmann G et al. (1993). *J Biomech*, 26: 969-990
Bergmann G et al. (2001). *J Biomech*, 34: 859-871
Burr D et al. (1997). *JBMR*, 12: 6-15
Chang P et al. (1999). *J Biomech Eng*, 121: 304-310
Moore and Gibson (2003). *J Biomech Eng*, 125: 761-768
Rho J et al. (1993). *J Biomech*, 26: 111-119
Santner T et al. (2003). *The Design and Analysis of Computer Experiments*. NY, Springer
Shimmin A et al. (2005). *Orthop Clin N Am*, 36: 187-193