INTRODUCTION

Retrograde femoral nailing for femoral shaft fractures has been used in its present form since approximately 1995. A rod is placed into the medullary canal through an entry site in the knee, extending into the subtrochanteric region of the proximal femur. Little is known regarding the implant’s effect on strain in the proximal femur. Report of fracture at the tip of the nail has occurred in shorter retrograde nails that end in the mid-diaphysis (Leibner et al., 1999). Other implanted devices which end in the subtrochanteric region, such as femoral neck pins and short antegrade intramedullary nails, have a well-established history of increased fracture risk (Andrew and Thorogood, 1984). This study examines strain changes incurred in the proximal femur before and after retrograde nailing, using a three dimensional finite element model.

METHODS

A three dimensional solid model of a commercially available synthetic femur (Sawbones, Pacific Research Laboratories, Vashon, WA, USA) was constructed using public domain surface geometries for The Standardized Femur (Viceconti, 1997). A mesh of 8 node hexahedral elements, with intervals of 3mm, was constructed for cortical and cancellous bone from the femoral head to the distal femoral metaphysis (31,600 elements). An intramedullary retrograde rod was modeled to fit the inner curvature of the femur with a constant 11mm diameter. Material properties were modeled as linear, elastic, isotropic, and homogeneous. The elastic modulus was defined as 14,200 MPa for cortical bone (McNamara et al., 1997), 1500 MPa for cancellous bone (Duda et al., 1998), and 200,000 MPa for the stainless steel rod (manufacturer); Poisson’s ratio was 0.3 for all materials. A femoral shaft fracture was simulated by creating a segmental defect at the mid-diaphysis. The distal end was fully constrained.

Axial Loading: The femur was loaded in a simulated single limb stance with the femur positioned in 25° adduction (Sim et al., 1995) and a load of 2000N distributed over the femoral head. An abductor force of 1240N was applied on the greater trochanter at 40° from the long axis of the femur (McNamara et al., 1997). The maximum (tensile) and minimum (compressive) principal strains were recorded laterally and medially in the intact femur and for nails with the proximal tip ending 2cm above the lesser trochanter (LT), at the LT, and 4cm below the LT.

Torsional Loading: A moment of 20 N-M was applied about the z axis, centered proximally around the long axis of the femur. Maximum shear strain was recorded at the same locations as for axial loading.

RESULTS AND DISCUSSION

Axial Loading: In the intact femur (no rod in place), minimum principal strains recorded along the medial proximal femur ranged from 2100 to 3300 με, with the highest strains immediately below the LT. Laterally, maximum principal strains ranged from 2100 to 2700 με, also with the highest strains just below the LT. For all nail lengths, strains decreased by less than 5% proximal to the tip of the nail (Figure 1). With the tip at 4cm below the LT, strains distal to the nail decreased up to 15% medially and 20% laterally. With the tip at the LT, strains distal to the nail decreased 12 to 15% medially and up to 27% laterally. With the tip of the nail
2cm above the LT, medial and lateral strains decreased more than for the other two nail lengths. Distal to the nail, medial strains decreased 8% at the LT and 10-15% 4cm below the LT, while laterally the strains decreased by 34% near the LT and equilibrated to a 20% decrease further distally.

**Torsional Loading:** All nail placements behaved similarly for medial shear strain (Figure 2). At 4cm below LT, minimal decrease in shear strain was observed (2 to 5% in all cases). At the LT, strains were increased by 17 to 18% compared to the intact femur for all nail positions. Shear strains increased by 34% for all nails at 2cm above LT. Lateral shear strains demonstrated similar behavior for all nails except in the region between 2cm above the LT and 4cm below the LT. In this region, progressively higher strains were observed as the nail was made shorter (Figure 2).

**SUMMARY**

Varying the length of a retrograde femoral nail alters the strain distribution in the proximal femur in this 3-D finite element model. During axial loads, progressively more stress shielding was observed, especially laterally, when the length of the nail was increased. The shortest nail had the least alteration in strain compared to the intact femur. In torsion, progressively higher shear strain was observed laterally at the LT and below for progressively shorter nails. Placing the tip of the nail more proximal may potentially protect the femur from fractures in the subtrochanteric region, but it will also predispose this region to stress shielding, which could be deleterious over time.

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**REFERENCES**


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**Figure 1:** Axial load with minimum (medial) and maximum (lateral) principal strains along the proximal femur plotted as percent of intact (refer to RESULTS section).

**Figure 2:** Torsional load of the femur with maximum shear strain plotted as percent of intact (refer to RESULTS section).