Published in final edited form as:

Curr Orthop Pract. 2010 August 12; 21(4): 385–389. doi:10.1097/BCO.0b013e3181d73bae.

Biomechanical strain analysis of the proximal femur following retrograde intramedullary nailing

David J. Hak¹, Rafael Neiman², and Scott Hazelwood, Ph.D.³

¹Denver Health / University of Colorado, Denver, Colorado

²Orthopaedic Trauma Surgeons of Northern California, Roseville, California

³California Polytechnic State University, San Luis Obispo, California

Abstract

Background—The purpose of this study was to examine the influence of proximal retrograde intramedullary nail position on proximal femoral strain, since stress risers occurring at the end of an implant can increase fracture risk.

Methods—Proximal femoral strains during axial and torsional loading were measured in composite Sawbone femurs after placement of retrograde intramedullary nails that ended at three different locations (2 cm proximal, 4 cm distal, and at the level of the lesser trochanter).

Results—No statistically significant difference was found between the axial or torsional strain observed in the intact femur and that seen after placement of a retrograde femoral nail ending at any of the three positions. Gages proximal to the nail tip demonstrated higher strains than the strains for the intact femur when compared with gages distal to the nail tip.

Conclusion—The ending location of a retrograde nail in the proximal femur does not appear to significantly alter strain in the proximal femur under the axial and torsional loading methods used in the study.

Keywords

retrograde femoral nail; proximal femoral strain; biomechanics

INTRODUCTION

Retrograde nailing has become increasingly common in the treatment of a variety of femoral shaft fractures. The relative indications for retrograde nailing in patients are broad, and include obesity, multiple injuries, pregnancy, ipsilateral femoral and tibial shaft fractures, and ipsilateral femoral neck and shaft fractures.^{1–5} Anatomic studies have shown that screws placed above the level of the lesser trochanter minimizes the risk to nerves and vascular structures.⁶

Correspondence to: David J. Hak, M.D., M.B.A., Associate Professor, Denver Health, 777 Bannock Street, MC 0188, Denver, CO 80204, Tel. (303) 436-6403, Fax. (303) 436-6572, david.hak@dhha.org.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Little has been reported about the effect of retrograde femoral nails on strain in the proximal femur. It is known that the subtrochanteric femur is an area of high strain.⁷⁻⁹ Implants used for fixing subtrochanteric femoral fractures are subject to high loads and fatigue failure. Two implant constructs are known to have an increased rate of fracture in the proximal femur. Femoral neck pins that are started distal to the level of the lesser trochanter have an increased risk of fracture.^{10,11} Fractures also have been reported at the distal tip of short antegrade femoral hip nails.¹²⁻¹⁴ These fractures occur as a result of stress concentration either at the tip of the device or through bone defect near the end of the implant (drill holes). A recent biomechanical study examined the effect of locked distal screws in retrograde intramedullary nailing using moderately osteopenic cadaveric femurs. When loaded to failure, half of the specimens sustained a subtrochanteric fracture through the proximal interlocking screw hole. Based on this study the authors recommended avoiding ending a retrograde intramedullary nail below the level of the lesser trochanter to avert proximal femoral stress risers and possible fractures.¹⁵

The purpose of this study was to examine the strain distribution of the proximal femur after retrograde intramedullary nail placement ending at one of three positions: 2 cm proximal to the lesser trochanter; at the level of the lesser trochanter; and 4 cm distal to the lesser trochanter.

MATERIALS AND METHODS

Ten composite 3rd generation Sawbone® femurs (Pacific Research Labs, Vashon, Washington, USA), which are designed to replicate the mechanical properties of young adult human femurs, were used.^{16,17} The synthetic bones were selected to eliminate the broad variability that exists in cadaveric specimens. These synthetic femurs are composed of a polyurethane foam core that simulates the mechanical properties of young adult human cancellous bone, covered with a short-glass-fiber-reinforced epoxy that simulates the mechanical properties of young adult human cortical bone. The synthetic cortical bone has an average density of 1.64 g/cc and an average compressive strength of 157 MPa. The synthetic cancellous bone has an average density of 0.27 g/cc and an average compressive strength of 4.8 MPa.

The distal ends of the femora were potted co-linearly in polymethylmethacrylate (PMMA) bone cement. An access hole was maintained distally for insertion and removal of three different length retrograde intramedullary nails. The intramedullary canal was sequentially reamed to 12 mm. Three anterior-to-posterior screws holes were drilled at defined locations in the proximal femur using a custom jig. Preliminary testing showed that the addition of these screw holes did not affect the specimen strain at the measured locations.

Strain gauges (Measurement Group, Raleigh, North Carolina, USA) were bonded to the synthetic femurs. The strain gauges were positioned both medially and laterally at three locations: 2 cm proximal to the lesser trochanter; at the level of the lesser trochanter; and 4 cm distal to the lesser trochanter. The medial gauges were stacked 45° rosettes to measure axial and shear strain at these locations, while the lateral gages were uniaxial to measure longitudinal strain on this surface. Data were collected using an Instron 1122 uniaxial testing machine (Instron, Canton, Massachusetts, USA) and an analog-to-digital signal processor (Keithley Metrabyte, Taunton, Massachusetts, USA) connected to a standard personal computer.

Each specimen was initially tested without an intramedullary nail. Three different length retrograde intramedullary nails were then inserted sequentially into each specimen in a randomized order. Each nail was distally interlocked, and then proximally interlocked with a

single anterior-to-posterior locking screw placed through one of the three prior drilled screw holes. The different size nails used were a 38-cm nail that ended 2 cm proximal to the lesser trochanter, a 36-cm nail which ended at the level of the lesser trochanter, and a 32-cm nail that ended 4 cm distal to the lesser trochanter. Since each nail length was tested in each specimen, 10 sets of data were available for each nail length.

For axial testing, an 11° wedge was positioned below the femur to orient the specimen in single-leg stance (Figure 1). The distal end of the potted femur was fixed to a linear bearing table, which allowed translation in the plane perpendicular to the axis of loading to minimize non-physiologic bending moments. For axial loading, the Instron crosshead was fitted with a molded concave acetabular cup whose surface matched the femoral head contour. Axial loading on the head of the femur was performed at a rate of 5 mm per minute to a maximal load of 2000N. Maximal compressive (medial) and tensile (lateral) strain values from the strain gauges were collected and analyzed at the peak force of 2000N.

For torsional testing, the femur and potting jig were positioned with the femoral shaft in a neutral position (Figure 2). The proximal femoral head and proximal greater trochanter were held in a custom made PMMA mold that matched the specimen contours. The distal end of the femur was rigidly fixed to the torsion frame. Torsion was induced through a pulley by linear pull using the Instron crosshead on a cable attached to the PMMA fixture. Torsional loading to 20 Nm along the femur's long axis was applied in a ramp fashion at 5 mm per minute. Shear strains were collected from the rosette strains gauges on the medial surface and analyzed at the peak torsional load of 20 Nm.

Statistical analysis using a repeated measures ANOVA with significance level of $P < 0.05$ was performed (Statview, SAS, Cary North Carolina, ISA). The two factors analyzed were gauge location and nail length. A Tukey post-hoc analysis was performed to check if strains at each gauge location were significantly different for differing nail lengths.

RESULTS

Axial Loading

For the 36-cm nail ending at the lesser trochanter, maximal compressive strains recorded along the medial proximal femur were within 5% of the strains recorded on the intact femur at each gauge location (Figure 3), with no statistical difference ($P > 0.05$). For the 32-cm nail ending 4 cm distal to the lesser trochanter, all medial gauges showed a trend of increased strain compared with intact femurs, while for the 38-cm nail ending 2 cm proximal to the lesser trochanter, all medial gauges showed a trend of decreased strain compared with the intact state. These differences were not statistically significant ($P > 0.05$).

The results were similar at the lateral gauge locations (Figure 4). Maximal tensile strains for the 36-cm nail ending at the lesser trochanter recorded along the lateral proximal femur were within 5% of the intact strains at each gauge location and were not statistically different. As with the medial gauge locations, the 32-cm nail ending 4 cm distal to the lesser trochanter exhibited a trend of increased lateral axial strains compared with the intact condition at each gauge location, but the differences were not statistically significant.

Torsional Loading

For the two conditions with the nail ending at or 2 cm proximal to the lesser trochanter, strains were within 7% of the intact femur for all gauges, with no statistical differences (Figure 5). The gauge located proximal to the nail tip demonstrated higher strains compared with the strains for the intact femur when compared to the gauge located distal to the nail tip. The 32-cm nail ending 4 cm distal to the lesser trochanter showed a trend of increases in

shear strain compared with the intact femur, increasing nearly 10% proximal to its nail tip during torsion. Similar to the axial loading condition for the 32-cm nail ending 4 cm distal to the lesser trochanter, all gauges showed increases in strain compared with intact strains, although the differences were not statistically significant.

DISCUSSION

In this biomechanical strain study using composite Sawbone® femurs we found that placement of a retrograde femoral nail altered the proximal femoral strain compared with the intact femur; however, these changes were not statistically significant. Proximal femoral strains were consistently higher in nails ending below the level of the lesser trochanter. However, when comparing differing nail positions at each gauge location, no statistical difference could be demonstrated between nails ending at the three different locations studied.

The clinical concern that led us to perform this study was the potential of a stress-riser induced fracture occurring at the proximal end of a retrograde femoral nail. The decrease in strain could potentially pose problems over time as the population ages and these implants are used in increasing numbers. Stress shielding may occur, which, in the presence of hardware removal after long-term implant presence, may potentially predispose the patient to a higher risk fracture. Although fractures proximal to retrograde femoral nails have not been reported as significant complications, cases have been reported in which a fracture occurs through a lateral interlocking screw site in short retrograde nails.¹⁸ A biomechanical study by Tejwani et al.¹⁵ led the authors to caution against ending a retrograde intramedullary nail below the level of the lesser trochanter. In their study using moderately osteopenic cadaveric femurs, half of the specimens sustained a subtrochanteric fracture through the proximal interlocking screw hole when loaded to failure.

In several clinical series^{2–4} complications of retrograde femoral nailing have included infection, knee pain, malunion, and nonunion. Although Moed and Watson³ acknowledged the theoretical possibility of increased fracture risk around the tip of the nail or its proximal interlocking screw, this has not borne out in several clinical series with the current implants, as it has with other implants ending in the same region, such as femoral neck screws or short antegrade nails.^{10–14} The reasons for failure in these implants may more likely be associated with the location of the stress risers. For many short antegrade nails, the distal interlocking screws are placed laterally with a jig, rather than from anterior to posterior. Similarly, femoral neck fixation screws also are placed along the lateral cortex of the proximal femur. The screw holes for short antegrade nails and femoral neck screws also are larger in diameter, and additional misplaced drill holes may have a more profound effect when located laterally. The strains on the anterior and posterior surfaces are 60–70% lower than those medially and laterally,^{16–19} thus drill holes placed from anterior to posterior may have a less detrimental mechanical effect on the proximal femur.

There are several limitations to this study. Preliminary testing indicated that the initial placement of three anterior-to-posterior drill holes did not affect the measured strains in the intact femur, which lead us to sequentially evaluate three nail ending positions in each specimen. This decision was driven mainly by cost constraints, and ideally each nail ending position would have been tested in a single specimen with a single proximal drill hole. We did not load the specimens to failure, since in a preliminary investigation we found that the composite bones failed through a vertical fracture of the femoral neck rather than through the subtrochanteric region. The synthetic composite bones that we used simulated healthy young adult bone rather than osteopenic bone. Significant differences may have been found had an osteopenic bone model been used, including a high proportion of subtrochanteric

fractures when loaded to failure as reported by Tejwani et al.¹⁵ Finally, we studied only two methods of loading, axial single leg stance and torsion, which we felt were the most relevant parameters for the proximal femur. We did not examine other loading methods and no muscle loads were simulated in this experiment.

A trend towards increased proximal femoral strain was observed with retrograde femoral nails that ended 4 cm distal to the lesser trochanter; however, the immediate effect was not significantly different from the nails that ended above the level the lesser trochanter. The differences in proximal femoral strains observed in this study do not raise concern for altering the practice of retrograde nailing, but do identify the need for further long-term studies assessing this implant's effect on the proximal femur over time.

Acknowledgments

Financial Support was received in part from NIH grant AR41644 and University of California at Davis, Department of Orthopaedic Surgery. Implants were donated by Zimmer Corporation (Warsaw, Indiana, USA).

REFERENCES

1. Gregory P, DiCicco J, Karpik K, et al. Ipsilateral fractures of the femur and tibia: treatment with retrograde femoral nailing and unreamed tibial nailing. *J Orthop Trauma* 1996;10:309–316. [PubMed: 8814571]
2. Moed BR, Watson JT. Retrograde intramedullary nailing, without reaming, of fractures of the femoral shaft in multiply injured patients. *J Bone Joint Surg* 1995;77(A):1520–1527. [PubMed: 7593060]
3. Moed BR, Watson JT. Unreamed retrograde intramedullary nailing of fractures of the femoral shaft. *J Orthop Trauma* 1998;12:334–342. [PubMed: 9671185]
4. Ostrum RF, DiCicco J, Lakatos R, Poka A. Retrograde nailing of femoral diaphyseal fractures. *J Orthop Trauma* 1998;12:324–329. [PubMed: 9671183]
5. Ricci W, Bellabarba C, Evanoff B, et al. Retrograde versus antegrade nailing of femoral shaft fractures. *J Orthop Trauma* 2001;15:161–169. [PubMed: 11265005]
6. Riina J, Tornetta P, Ritter C, Geller J. Neurologic and vascular structures at risk during anterior-posterior locking of retrograde femoral nails. *J Orthop Trauma* 1998;12:379–381. [PubMed: 9715443]
7. Evans FG, Lissner HR. Stresscoat deformation studies of the femur under static vertical loading. *Anat Rec* 1948;100:159–190. [PubMed: 18898776]
8. Evans FG, Pedersen HE, Lissner HR. The role of tensile stress in the mechanism of femoral fractures. *J Bone Joint Surg* 1951;33(A):485–501. [PubMed: 14824200]
9. Duda G, Heller M, Albinger J, et al. Influence of muscle forces on femoral strain distribution. *J Biomech* 1998;31:841–846. [PubMed: 9802785]
10. Andrew T, Thorogood M. Subtrochanteric fracture after Garden screw fixation: a review of predisposing factors and management in nine cases. *Injury* 1984;16:169–177. [PubMed: 6490155]
11. Howard C, Davies R. Subtrochanteric fracture after Garden Screw Fixation of Subcapital Fractures. *J Bone Joint Surg* 1982;64(B):565–567.
12. Halder SC. The Gamma nail for peritrochanteric fractures. *J Bone Joint Surg* 1992;74(B):340–344.
13. Lacroix H, Arwert H, Snijders C, Fontijne W. Prevention of fracture at the distal locking site of the Gamma nail. A biomechanical study. *J Bone Joint Surg* 1995;77(B):274–276. [PubMed: 7844136]
14. Williams WW, Parker BC. Complications associated with the use of the Gamma nail. *Injury* 1992;23:291–292. [PubMed: 1644453]
15. Tejwani NC, Park S, Iseaka K, Kummer F. The effect of locked distal screws in retrograde nailing of osteoporotic distal femur fractures: a laboratory study using cadaver femurs. *J Orthop Trauma* 2005;19:380–383. [PubMed: 16003196]
16. Cristofolini L, Viceconti M, Capello A, Toni A. Mechanical validation of whole bone composite femur models. *J Biomech* 1996;29:525–535. [PubMed: 8964782]

17. Heiner AD, Brown TD. Structural properties of a new design of composite replicate femurs and tibias. *J Biomech* 2001;34:773–781. [PubMed: 11470115]
18. Leibner E, Mosheiff R, Safran O, Abu-Snieneh K, Liebergall M. Femoral fracture at the proximal end of an intramedullary supracondylar nail: a case report. *Am J Orthop* 1999;29:53–55. [PubMed: 10048361]
19. Kim Y-H, Kim J-S, Cho SH. Strain distribution in the proximal human femur. *J Bone Joint Surg* 2001;83(B):295–301.

Figure 1.
Axial loading of a synthetic specimen with three sets of rosette strain gages attached medially, and three sets of axial strain gages attached laterally.

Torsional Load-Medial Gages

Figure 2.

Torsional loading of a synthetic specimen mounted in a custom test fixture. The distal end of the femur is fixed. The proximal femur is mounted to a pulley that is attached to the crosshead of the material testing machine, allowing the femur to be rotated about its longitudinal axis.

Figure 3. Compressive strain values at the medial gages during axial loading. (LT+2 = gage located 2 cm proximal to lesser trochanter, LT = gage located at level of lesser trochanter, LT-4 = gage located 4 cm distal to lesser trochanter)

Figure 4.

Tensile strain values at the lateral gages during axial loading. (LT+2 = gage located 2 cm proximal to lesser trochanter, LT = gage located at level of lesser trochanter, LT-4 = gage located 4 cm distal to lesser trochanter)

Axial Load-Lateral Gages

Figure 5.

Shear strain values at the medial gages during torsional loading. (LT+2 = gage located 2 cm proximal to lesser trochanter, LT = gage located at level of lesser trochanter, LT-4 = gage located 4 cm distal to lesser trochanter)