Does Screw Configuration Affect Subtrochanteric Fracture after Femoral Neck Fixation?

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A subtrochanteric femur fracture after cannulated screw fixation of a femoral neck fracture is a devastating complication. We hypothesized that an apex-distal screw orientation would tolerate higher loads to subtrochanteric fracture. Human cadaveric femora were instrumented with three cannulated screws in either an apex-distal or an apex-proximal configuration. Specimens were loaded along the mechanical axis to failure creating a subtrochanteric femur fracture. Ultimate load to failure and the effect of bone density on load to failure were compared between groups. There was a greater load to failure in the apex-distal group compared with the apex-proximal group. The mean force to fracture in the apex-distal group (11,330 N; standard deviation = 3151 N) was greater than the mean force to fracture in the apex-proximal group (7795 N; standard deviation = 3194 N). Previous investigations have shown improved femoral neck fixation with an apex-distal configuration, but none has examined the relationship between screw orientation and subtrochanteric fractures. Our observations support the use of an apex-distal configuration for cannulated screw fixation of femoral neck fractures.

Subtrochanteric femur fractures after pin or screw fixation of femoral neck fractures have been documented in all age groups.2,8,11,14,16,17 These typically transverse or short oblique fractures are the result of minimal trauma and have been reported to occur from 1 week to 2 years after femoral neck fracture fixation.2,8,9,17,20 This complication may be attributed to several factors. Previous investigators suggested that starting points below the level of the lesser trochanter, screws placed too close together, and violation of the lateral cortex with multiple guide-wire passes contribute to this complication.8,11,20 The common theme in all of these investigations is the creation of a stress riser along the lateral aspect of the proximal femur where tensile forces are substantial.1 Pelet et al reported subtrochanteric fracture after placement of two screws of a triangular configuration in the inferior femoral neck despite placement above the level of the lesser trochanter.17 We also have experienced this after placing two of three screws in the distal portion of the triangle (Fig 1). To our knowledge, no biomechanical studies have been done to determine if there is a correlation between subtrochanteric femur fracture and cannulated screw orientation.

Although this has not been supported clinically,13 biomechanical studies of femoral neck fractures advocate fixation with three screws in a triangular configuration,4,15,18 and this is common practice in North America. However, postoperative radiographs of femoral neck fracture fixation in orthopaedic journals and texts show a lack of consensus regarding the apex of the triangular configuration on the lateral femoral cortex.2,6,9,11,16,20

We hypothesized that a triangular screw configuration with its apex distal would withstand greater forces before subtrochanteric fracture than an apex-proximal configuration. We think a larger stress riser is created when two screws are placed distally (because of the larger cortical defect), and fracture will occur at lower loads in this area of high tensile forces. Therefore, we developed a novel method specifically to test the configuration of screw placement as it relates to subtrochanteric femur fracture as a complication.

MATERIALS AND METHODS

Six matched pairs of human cadaveric femora were obtained, and radiographs were taken to exclude those with pathologic
conditions of the bone. Quantitative computed tomography was
done at the subtrochanteric region to measure cortical bone min-
eral density and cortical cross-sectional area (Norland Stratec,
Norland Medical Systems, Fort Atkinson, WI). Frozen speci-
mens were thawed, stripped of all soft tissues, and randomly
assigned to two groups corresponding to two different screw
configurations used for femoral neck fracture fixation.

Three cannulated screws were placed in an equilateral tri-
gle in either an apex-proximal (AP) or apex-distal (AD) con-
figuration (Fig 2). A line was drawn at the level of the lower
extent of the lesser trochanter on each femur. A Synthes (Paoli,
PA) 7.0-mm cannulated screw set was used for all instrumen-
tation. Terminally threaded guide wires (2.0 mm) were inserted
in parallel, through a triangular drill guide, across the femoral neck
beginning at the line marking the inferior extent of the lesser
trochanter. For the contralateral femur, the drill guide was
reversed and the opposite orientation was used. Again, the distal
guide wire(s) entered the lateral cortex at the level of the line
marking the lower extent of the lesser trochanter. Single cortical
perforations were made during insertion of the guide wires to
ensure that the subtrochanteric fractures were not caused by an
empty hole from a guide-wire pass. The guide then was re-
moved, and a 4.5-mm cannulated drill was passed over the guide
wire(s). The bone was tapped, and 7.0-mm partially threaded,
cancellous screws of appropriate length were inserted by hand
tightly and the distal
screw insertion force was not determined or controlled during
the experiment to simulate clinical application. One surgeon did
screw placement for all specimens.

The femur then was placed in a tub with the head in contact
with a metal hemisphere. The femoral shaft was cut perpendicu-
lar to its mechanical axis 14 cm distal to the lesser trochanter
(Fig 3A). The femur was aligned along its mechanical axis. The
head and neck region was potted using cement, and the distal
portion of the cut femur was secured with threaded Steinmann
pins. The specimen was loaded along the mechanical axis to
failure, resulting in uniform creation of subtrochanteric femur
fractures. The specimen was loaded at 1000 N/second along the
mechanical axis until failure on an MTS machine (858 mini
Bionix, Minneapolis, MN) (Fig 3B).

A paired, one-tailed t test was used to analyze the load to
failure data of the two screw configurations. A linear regression
analysis was performed with the bone mineral density and the
cross-sectional area as the independent variables and load to
failure data as the dependent variable. The Systat 10.2 software
package (Systat Software Inc., Richmond, CA) was used to do
the statistical analyses. A p value < 0.05 was considered statis-
tically significant.
RESULTS

The apex-distal configuration had a greater load to subtrochanteric fracture than the apex-proximal configuration (Table 1). The mean force to fracture in the apex-distal group (11,330 N; SD = 3151) was greater (p = 0.01) than the mean force to fracture in the apex-proximal group (7795 N; SD = 3194). The mean (± SD) difference in load to failure between the two groups was 3535 N (± 2744 N) (95% CI, upper, 6415 N; lower, 655 N).

We detected no relationship between load to failure and cortical bone mineral density or cross-sectional area (Table 1). There was increasing load to failure in the apex-distal group with increasing bone density (R² = 0.52; p = 0.11) that was not present in the apex-proximal group (R² = 0.13; p = 0.48) (Table 1). A power analysis of a multiple linear regression of a sample of six specimens provided a power of only 0.48. At least 10 specimens would be necessary to make a statement with a power of 0.80.

All fractures, regardless of screw configuration, originated from the distal-most screw(s) and were either a transverse or short-oblique pattern. In the apex-distal group, deformation was seen in the single distal screw along the calcar after failure; less deformation occurred with two distal screws in the apex-proximal group.

DISCUSSION

A subtrochanteric femur fracture can be a serious complication after femoral neck fracture fixation with cannulated

![Fig 3A-B.](image)

(A) The specimen is aligned along the mechanical axis. (B) This photograph shows a specimen in the MTS machine.

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Failure Load Apex-distal (number)</th>
<th>Failure Load Apex-proximal (number)</th>
<th>Cortical Bone Density (mg/cm³)</th>
<th>Cross-sectional Cortical Area (mm²)</th>
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<td>15,000*</td>
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<td>507</td>
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<td>2</td>
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<td>9819</td>
<td>5444</td>
<td>1121</td>
<td>512</td>
</tr>
<tr>
<td>6</td>
<td>13,519</td>
<td>8683</td>
<td>1078</td>
<td>604</td>
</tr>
</tbody>
</table>

Mean (SD) 11,330 (3151) 7795 (3194) 1097 (50) 486 (84)

*The specimen did not fail before the load cell limit was reached; SD = Standard deviation.
screws. The second, more extensive revision surgery is reported to have an associated 20% mortality rate. These fractures typically result from a low-energy mechanism and produce a transverse or short oblique pattern. We think creation of a stress riser at the proximal, lateral femoral cortex is the cause of these fractures and is influenced by screw configuration. We hypothesized that a triangular screw configuration with its apex distal would withstand greater forces before subtrochanteric fracture than an apex-proximal configuration. Therefore, we developed a novel method to test our hypothesis and found the apex-distal configuration tolerated greater loads before fracture.

There are several limitations. First, we assumed subtrochanteric femur fractures after cannulated screw fixation could be caused by axial load along the mechanical axis alone. Clinically, there may be other forces acting on the proximal femur producing these fractures. A protocol was designed and attempted using an axial load of 2500 N and up to 50 N-m torsion, which represented the limits of biaxial application of loads with our MTS machine; however, no subtrochanteric fractures were produced. It is unclear if these fractures result from torsion, axial load, bending, or a combination of loads. The correct combination and magnitude of loads that clinically cause a subtrochanteric fracture in this setting are unknown. Differing combinations likely decrease the magnitude of a force needed to cause a subtrochanteric fracture. This may help explain the large amount of force necessary to produce this event using application of an axial load along the mechanical axis alone. However, we were able to reliably create subtrochanteric fractures with transverse or short oblique fracture patterns using this loading condition in our model (Fig 4).

Second, we did not use a previously described femoral neck fracture model for our study. Initial attempts were made to recreate previously described femoral neck fracture models. This resulted in fixation failure, therefore prohibiting evaluation of screw configuration on subtrochanteric femur fractures. We were not surprised to find that fixation failure was easier to achieve than a subtrochanteric fracture. However, our goal was not to test the quality or strength of femoral neck fracture fixation, but to detect a difference in the load needed to create a subtrochanteric fracture using different screw configurations. Therefore a femoral neck fracture model was not necessary to answer our question, and we used intact specimens potted across the femoral neck to concentrate forces to the peritrochanteric region.

Third, cadaveric specimens and limited test configurations cannot account for all of the biomechanical possibilities present in a patient who is walking. Posttraumatic osteopenia secondary to limited weightbearing and activity modification may have an effect we could not account for in our experiment. We used fresh-frozen specimens and randomized the pairs of femora to each study group to eliminate selection bias. Six specimens were sufficient to achieve statistical significance when looking at the mean load to failure between groups. We made the assumption that these data are applicable to the population of patients who sustain these fractures. Additionally, more specimens may have stratified the data when looking at the increasing load to failure with increasing bone density seen in the apex-distal group that was not seen in the apex-proximal group.

Numerous recommendations have been proposed concerning the technical aspects of pinning femoral neck fractures using three cannulated screws. Pelet et al, in a study of four subtrochanteric femur fractures after cannulated screw fixation, recommended anatomic closed reduction, minimizing guide-wire passes, using the lowest possible angle of insertion (starting point above the lesser trochanter), parallelism of screws, subchondral bone fixation in the head, three screws, starting screws as far apart as possible, and placing screws in an inverted triangle configuration. Subtrochanteric fractures have been reported despite these recommendations when an apex-proximal orientation was used.

Fractures occurring at variable times from fixation may result from the patient’s tolerance of force application to the injured limb after fixation, surgical variables (screw placement or multiple passes to perform fixation), bone quality, or, all of the above. A self-protection mechanism after open reduction and internal fixation of proximal femoral fractures has been reported and also may protect the subtrochanteric region in unstable patterns after fixation. This phenomenon may not occur in stable patterns after fixation or after union of the fracture. With stability or after union, surgical variables and bone quality may

Fig 4. A fractured specimen is shown in this photograph.
play a more important role in the occurrence of subtrochanteric fractures, making our model clinically applicable. The studies that support using an inverted triangle configuration were designed to investigate femoral neck fracture fixation strength and not subtrochanteric fracture as a complication.\(^4,15\) Booth et al\(^4\) recommended peripheral placement of screws in the femoral neck rather than central placement to improve the strength of fixation. Mizrahi et al\(^15\) specifically recommended an inverted triangle configuration as it was stronger than an upright triangular configuration. These two biomechanical studies illustrate that an apex-distal configuration with screws placed in subchondral bone resists failure better than screws placed in an apex-proximal configuration in the central, cancellous bone. In our study, deformation was observed in the single distal screw (apex-distal group) along the calcar after failure; less deformation occurred with two distal screws in the apex-proximal group. This is consistent with Mizrahi et al comparing femoral neck fracture stability between apex-proximal and apex-distal orientations.\(^3\) Deformation occurred in the single distal screw as prestress was maintained because of cortical bone purchase. The apex-proximal configuration was found to slip in the cancellous bone rather than bend because of the loss of prestress from insufficient cortical purchase in the most caudal position of the femoral neck. We know of no other study designed to investigate the relationship between cannulated screw configuration and a subtrochanteric femur fracture. The literature on femoral neck fracture fixation has largely been aimed at determining optimal fracture stability. Our study meant to determine if the triangular screw configuration used for femoral neck fracture fixation was relevant with respect to subtrochanteric fracture as a complication. Our data indicate that using an inverted triangle configuration (apex-distal) is less likely to result in a subtrochanteric femur fracture when compared with an apex-proximal configuration. If this is the case clinically, then there are two reasons for placing three screws in an apex-distal configuration with cortical bone support. Using the best configuration for femoral neck fracture stability is also the configuration least likely to lead to a subtrochanteric femur fracture. Based on these findings, we recommend using an inverted triangular configuration (apex-distal) for cannulated screw fixation of femoral neck fractures.

**Acknowledgment**

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**References**