Two-Screw Femoral Neck Fracture Fixation: A Biomechanical Analysis of 2 Different Configurations

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Abstract

In the study reported here, we evaluated 2-screw femoral neck fixation. Femoral necks from 5 paired fresh-frozen cadavers were fractured and then fixed with two 7.3-mm cannulated cancellous screws. Vertical (parallel screws in sagittal plane of femoral neck) and horizontal (parallel screws in superior aspect of femoral neck) configurations were used for each matched pair. Mechanical testing was performed. Load, displacement, and stiffness at the yield point were significantly higher in the horizontal group, which also had a higher mean maximal failure load (P = .019). Preliminary data suggest that 2 horizontal screws in the superior aspect of the femoral neck provide more secure fixation than 2 vertical screws.

Femoral neck fractures are among the most common fractures in the elderly, and the incidence is rising with the age of the population. By 2050, an estimated 500,000 hip fractures will be occurring annually in the United States.[1] Because conservative management is usually disappointing, operative treatment of these fractures is commonly recommended. The 2 most widely used treatment modalities are internal fixation and primary arthroplasty.[2-4] Internal fixation with cancellous screws may be the preferred treatment for a fractured hip that is not excessively displaced or osteoporotic.[5] Stability of fixation is in part determined by compression across the fracture site, which in turn is affected by bone density, screw purchase strength, and number and orientation of screws.

Several investigators have tried to determine the optimal number of screws and pins for fixation. Most orthopedic surgeons accept that placing 3 parallel screws into the femoral head will provide enough stability for most patients.[6-8] More than 3 may further insult the blood flow to the femoral head, which may lead to avascular necrosis and collapse. In addition, Swiontkowski and colleagues[7] showed no added biomechanical stability with more than 3 screws or pins. Fewer than 3 may provide inadequate fixation, leading to failure. However, not uncommonly, there may not be enough room for 3 screws in the femoral neck. In this case, the surgeon is left with little choice but to use only 2 screws. Given this scenario, is there a way to optimize fixation with different orientations of screw placement? In the study reported here, we evaluated 2-screw femoral neck fracture fixation using 2 different configurations.

MATERIALS AND METHODS

Ten proximal femora from 5 fresh-frozen cadavers were studied. Specimens were matched pairs. Mean age of donors was 77 years (range, 65-87 years). Four of the 5 donors were female. At time of death, no donor was known to have bone disease, other than that related to normal aging.

During the harvest, all soft tissues were removed, and the hip was disarticulated. The femoral shaft was osteotomized midlevel. The proximal femora were then frozen at –20°C and kept frozen until testing. Before testing, each specimen was thawed at room temperature for at least 2 hours.

After a neck was thawed, a partial superior corticotomy (stress riser) was performed to start a fracture, which was then completed by dropping a 5-kg weight from a height of 1.5 to 2 meters onto the femoral head. This reproducible method created a noncomminuted, midcervical femoral neck fracture. The fracture was then reduced and fixed with two 7.3-mm cannulated cancellous screws (Synthes, Paoli, Pa) using AO (Arbeitsgemeinschaft für Osteosynthesefragen) techniques. Provisional fixation was done first with guide wires. After the guide wires were inserted in the desired positions (as verified by an image intensifier), drilling was performed. The lateral cortex of the femur was then tapped, and screws of appropriate lengths were placed in compression.

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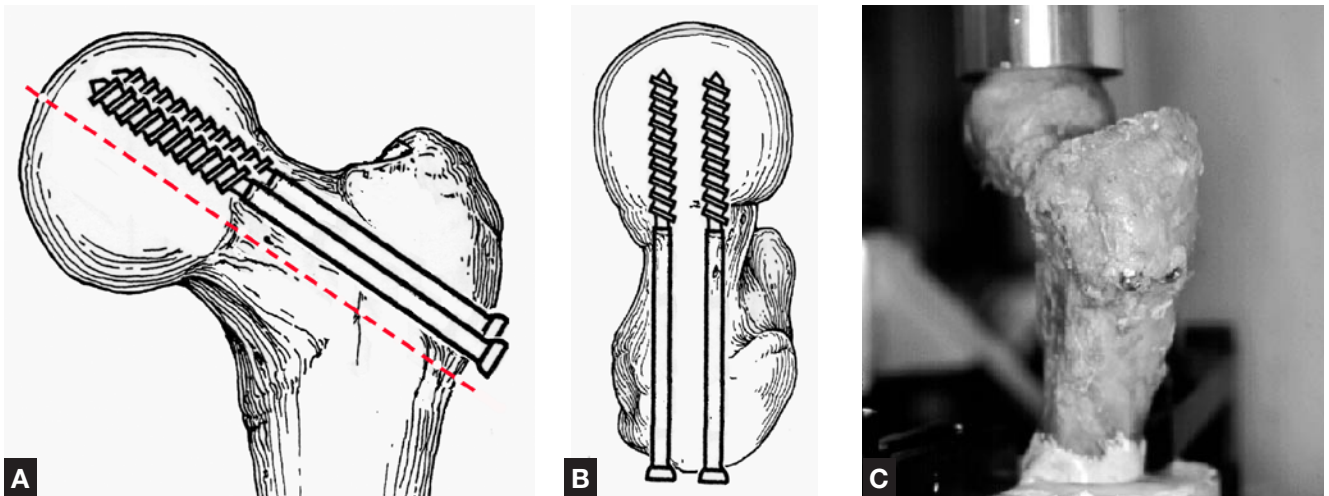
Figure 1. (A,B) Diagrams of proximal femur with 2 parallel screws in the horizontal orientation. Both screws are superior to the midaxis of the femoral neck and head (dotted line). **(C)** Specimen in the horizontal group undergoing mechanical testing. Copyright 2007, Virak Tan, MD. Printed with permission.
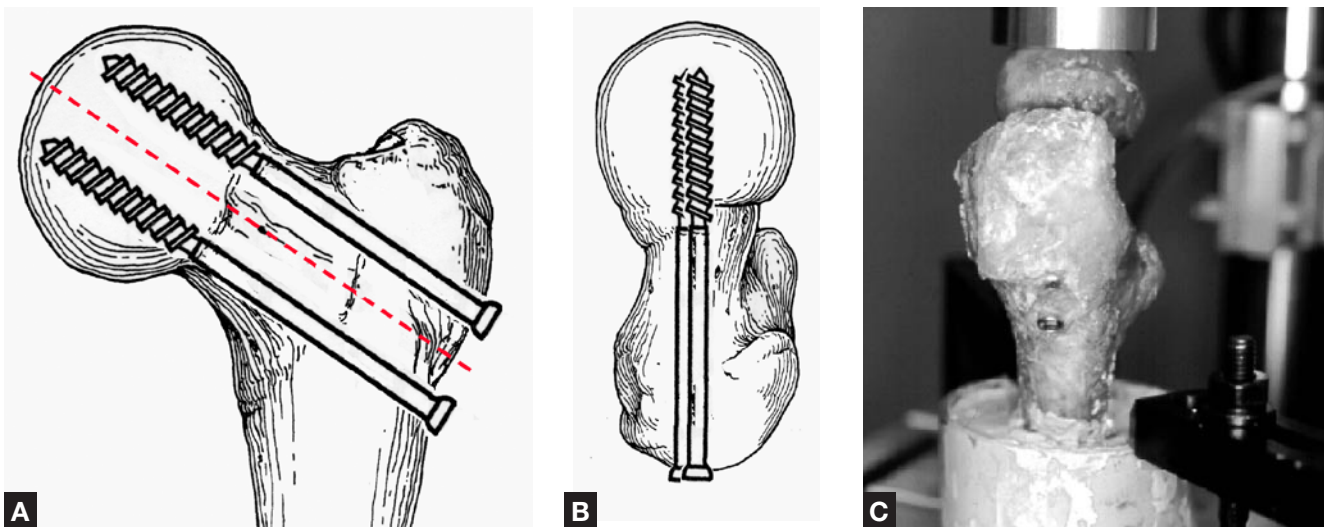

Figure 2. (A,B) Diagrams of proximal femur with 2 screws in the vertical orientation. The screws are parallel in the sagittal plane of the femoral neck. One screw is superior to, and the other is inferior to, the midaxis of the femoral neck and head (dotted line). **(C)** Specimen in the vertical group undergoing mechanical testing. Copyright 2007, Virak Tan, MD. Printed with permission.

Two different configurations (vertical, horizontal) were used for each matched pair (Figures 1, 2). The right proximal femur specimen was randomized to either vertical or horizon fixation, and the matched-pair left specimen received the other fixation configuration. Vertical pinning consisted of placing parallel screws, 1 superior and 1 inferior, in the sagittal plane of the femoral neck; horizontal pinning consisted of placing 2 parallel screws side by side in the superior aspect of the femoral neck. Final screw positions were confirmed with x-rays. After fixation, each femur was mounted in a testing jig at approximately 20° of adduction and 5° to 10° of flexion to simulate a single-phase stance. Mechanical testing was performed with an Instron Testing Machine 1331 (Instron, Canton, Mass), and the load-versus-deformation curve was recorded. The postfixation femora were initially subjected to cyclical axial loading of 750 N at 0.5 Hz for 200 cycles, and the vertical displacement of the proximal fragment at the end of cyclic testing (ie, fragment subsidence) was determined. Then the specimens were loaded to failure. The amounts of load and displacement of the fracture-fixation construct were recorded at the yield point and at the failure point. Stiffness was calculated by dividing load by displacement. All data were analyzed with Student t tests and pairwise comparisons and are presented as group means and SDs.

RESULTS

X-rays confirmed the absence of pathologic disease in the proximal femur of the specimens. Gross observation during testing revealed that specimens in the horizontal group failed with the collapse of the proximal fragment into varus. There was no screw backout in this group. The vertical group also

Figure 3. Representative inferior screw backout during mechanical testing of the vertically placed screws. Copyright 2007, Virak Tan, MD. Printed with permission.

failed in varus; however, the inferior screw backed out 1 cm or more in 4 of the 5 specimens (Figure 3). There was no cutout of the screws through the superior head in any specimen.

Mechanical testing results are summarized in the Table. Overall, mean vertical displacement of the proximal fragment during cyclic loading (subsidence) was 1.1 mm for all 10 constructs. There was no difference in vertical displacement between the horizontal and vertical screw groups. When the femora were loaded to failure, there were statistical differences between the 2 groups. At the yield point, load, displacement, and stiffness were significantly higher in the horizontal group. The horizontal group also had a higher mean maximal load (at failure) than the vertical group (3.75 vs 2.46 kN; P = .019), but there was no statistical difference in displacement or stiffness at failure. Furthermore, there was no side-to-side difference between the left and right hips (P>.3).

DISCUSSION

Femoral neck fractures continue to be common injuries. In 1990, there were 1.66 million hip fractures worldwide. That figure is expected to increase to 2.6 million by 2025.[9] From a public health standpoint, prevention is of utmost importance, but, once a fracture has occurred, surgical treatment is usually indicated. In the United States, a common practice is

closed reduction and pinning of the hip with 3 parallel screws. However, 2 screws may be more appropriate for small femoral necks, young children, and nondisplaced or stress fractures.[10] In some European countries,[11] 2-screw fixation is the standard of care. In these 2-screw cases, does screw configuration affect fracture stability? There is little in the literature in this regard. To our knowledge, only a few studies have examined screw configurations,[11-14] and none has examined 2-screw fixation with regard to horizontal versus vertical position, though Lindequist and colleagues[11] tested 2 screws in different vertical positions.

The present study was designed with internal controls to minimize individual specimen variations. Because matched pairs of femora were used, and the donors did not have bone disease, the issue of bone density variability was avoided. Our methodology of creating the fracture was reproducible and simulated the situation (a fall) in which most hip fractures occur.[15] We did not model fracture comminution because these types of fractures may be best treated with primary arthroplasty.[2]

A limitation of this study is that the testing modeled only a single-limb stance, which does not truly reflect the clinical situation of ambulation. Nevertheless, we believe our mechanical testing is valid because, early in the postoperative period, patients are obligated by pain to use ambulation-assistive devices and do not fully walk on the extremity. The cyclic loading aspect of the experiment simulated this state of partial weight-bearing to about 1 times body weight (one-third of normal hip forces). In addition, our mechanical tests were performed in a manner similar to that described in the literature.[8,12,16] Independent validation of our study comes from our load, displacement, and stiffness results falling within the ranges reported for other studies.[6,12] Finally, the small number of specimens tested limited the power of this study.

Our study data suggest that, from a biomechanical standpoint, screw configuration may be important in 2-screw femoral neck fixation. Two parallel screws horizontally placed in the superior aspect of the femoral neck provided significantly higher yield point and failure loads, 68% and 52%, respectively, when compared with the vertical 2-screw arrangement. A possible explanation for this finding may be that the pivot point of the proximal fragment

Table. Results of Cyclical and Load-to-Failure Biomechanical Testing of Femoral Neck Fractures*

	Group			
	Total	Horizontal	Vertical	*P*
Cyclical loading: creep (mm)	1.1±1.4 (0.2-4.6)	0.9±0.8 (0.2-2.3)	1.3±1.9 (0.2-4.6)	NS
Load to failure				
Load @ YP (kN)	1.65±0.73 (0.45-3.11)	2.07±0.65 (1.48-3.11)	1.23±0.59 (0.45-2.05)	.004
Displacement @ YP (mm)	1.47±0.55 (0.76-2.41)	1.70±0.57 (1.09-2.41)	1.23±0.49 (0.76-2.03)	.011
Stiffness @ YP (kN/mm)		1.28±0.36 (0.77-1.79)	1.04±0.41 (0.38-1.37)	.046
Maximal load at failure (kN)	3.10±1.59 (1.36-6.35)	3.75±1.57 (2.33-6.35)	2.46±1.49 (1.36-5.00)	.019
Displacement @ failure (mm)	4.45±1.91 (2.08-7.24)	5.23±1.73 (3.43-7.24)	3.66±1.92 (2.08-6.86)	NS
Stiffness @ failure (kN/mm)		0.76±0.35 (0.46-1.33)	0.80±0.49 (0.20-1.33)	NS

*Creep indicates displacement over time; YP, yield point; NS, not significant..

appears to be located on the inferior aspect of the femoral neck (in the region of the calcar and inferior cortical bone). This is largely based on the observation that constructs consistently failed by having the proximal fragment shifting, or tilting, into a varus position. Thus, the calcar region appeared to effectively serve as a fulcrum during loading and to allow for relative separation of the fragments to initially occur on the opposite (superior) side of the fracture line. Therefore, we hypothesize that fixation of this fracture pattern with 2 horizontal screws in the superior neck (tension side), and farther from the pivot point, may have distinct biomechanical advantages.

An inferior pivot point would appear to make sense in this scenario for at least 2 reasons. First, because there is compression on this side (inferior), there is a tendency for the fracture fragments to impact and rotate about this point. Second, there may be intact soft tissues on the inferior side, which will help to limit displacement in this region. The schematics in Appendices 1 and 2 show how screw placement may have influenced the stability of the constructs in this study. Using a standard Cartesian coordinate system, the force applied to the head of the femur (F_{hip}) during ambulation, or mechanical testing in this instance, can be resolved into 2 orthogonal vector components. One component is oriented parallel to the axis of the femoral neck and screws (F_{par}); the other is oriented perpendicular to the axis of the femoral neck and screws (F_{per}). The vector acting along the axis of the screws, F_{par}, tends to compress and therefore stabilize the 2 fragments. However, the perpendicular component creates both a bending moment and a shear force in the femoral neck and fixation hardware and therefore tends to destabilize the fragments. Therefore, considering the placement of the 2 screws with regard to how they may best resist the shear force and bending moment generated by F_{per} may provide some valuable insight.

The first assumption is that the tension in each screw, and therefore the compressive or clamping force generated by each screw, F_s, is equivalent. Following general fastener engineering principles, if identical screws are inserted in a similar manner and tightened to similar torques, this should hold true. Given this, screw position as examined in this study should not affect the stability of the fragments significantly when subjected to shear. The reason is that, under otherwise identical conditions (ie, contact areas and frictional coefficients), the factor primarily responsible for resistance to shear forces between the fragments is the net compressive force across the fracture line. However, bending moments present a different situation. In bending, screw location relative to fulcrum or neutral axis location influences the stability of the construct. In addition, as already described, the fulcrum or pivot point for the proximal fragment appears to be located on the inferior aspect of the femoral neck (Appendices 1, 2). Resistance to an applied bending moment, and therefore resultant fragment displacement, is provided by the effective moments generated by the screws. The moment generated by each screw is a function of the tensile force in each screw multiplied

by the screw's effective moment, or lever arm. Assuming that F_s is equal in each screw, the farther a given screw is located from the pivot point, the more effective it is in terms of resisting relative fragment movement as a result of imposed bending loads. On the basis of these concepts, we propose that placing the 2 screws horizontally (Appendix 2) provides for increased resistance to bending loads and is the primary reason for the significantly higher failure loads with this screw configuration. With the vertical configuration, 1 screw is placed much closer to the pivot point, thereby dramatically reducing its lever arm and making it much less effective with regard to resisting bending loads.

Another factor that may have contributed to increased maximal loads in the horizontal group is that both screws were placed into the superior quadrant of the femoral head, where there is increased subchondral bone density.[13,14] Thus, screws placed in this region likely have increased pull-out strength. Reduced bone purchase in the inferior femoral head region may also account for the inferior screw back-out often observed with the vertical configuration.

Several authors have suggested that screws placed with the support of cortical bone in the femoral neck or calcar provide better stability.[11,12] Although better stability has been shown in biomechanical tests, achieving this exact "ideal" construct in the clinical setting of the operating room may be less precise. That is, when surgeons try to make the screws abut the cortices, the already osteoporotic bone in the femoral neck becomes susceptible to perforations. Should cortical bone become perforated, the overall construct may become compromised because of stress riser.

A surprising finding in this study is that maximal displacement at failure was larger in the horizontal group. Although the 1.57-mm difference was not statistically significant, we had expected less displacement in the group with higher maximal loads. It may be that the horizontal configuration allowed for stabler displacement to sustain higher loads before ultimately failing. Clearly, further investigation is needed to determine how screw position relates to overall construct strength and stiffness.

We do not suggest that 2 and not 3 screws be used for femoral neck fracture fixation. However, when a situation calls for only 2, placing parallel screws horizontally in the superior aspect of the femoral neck and head may provide better fixation. Further studies with larger numbers of specimens are warranted to confirm or refute our preliminary findings.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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Appendix 1. Vertical Orientation

F_{hip} = force acting on hip joint.

Force vector F_{hip} can be represented as a sum of 2 smaller force vectors acting perpendicular (F_{per}) and parallel (F_{par}) to the screws.

F_{per} produces bending moments and shear forces that displace the fracture.

F_{par} generates a compressive force across the fracture line and tends to stabilize the fragments.

d_1 = effective lever arm for inferior screw.
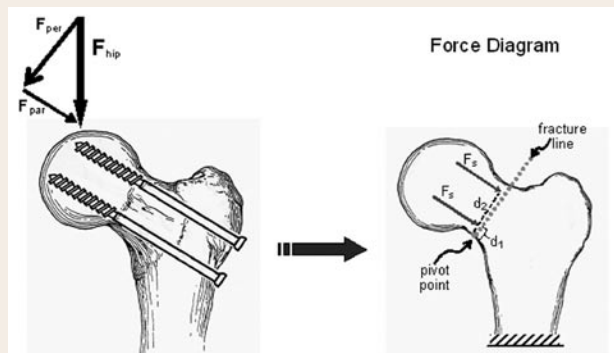
d_2 = effective lever arm for superior screw.

F_s = tensile force in each screw.

Moment = force x lever arm.

Combined effective moment (M_{eff}) of both screws in vertical arrangement:

$$M_{eff} = F_s \times d_1 + F_s \times d_2$$

$$M_{eff} = F_s (d_1 + d_2)$$

Appendix 2. Horizontal Orientation

F_{hip} = force acting on hip joint.

Force vector F_{hip} can be represented as a sum of 2 smaller force vectors acting perpendicular (F_{per}) and parallel (F_{par}) to the long axis of the screws.

F_{per} generates bending moments and shear forces that displace the fracture.

F_{par} generates a compressive force across the fracture line and tends to stabilize the fragments.

d_2 = effective lever arm for both screws.

F_s = tensile force in each screw.

Moment = force x perpendicular distance.

Combined effective moment (M_{eff}) of both screws in horizontal arrangement:

$$M_{eff} = F_s \times d_2 + F_s \times d_2$$

$$M_{eff} = F_s (2d_2)$$