# A Biomechanical Study of Simulated Femoral Neck Fracture Fixation by Cannulated Screws: Effects of Placement Angle and Number of Screws

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## Abstract

The angle of placement of hip screws to fix femoral neck fractures is still a controversial subject, and it must be addressed.

In the study reported here, we compared the relative stiffness of fixation of simulated Pauwels type III femoral neck fractures fixed with either 2 or 3 cannulated screws implanted at 135°, 145°, and 150°. Each femur was fixed with 2 or 3 cannulated screws and tested under axial loading and anteroposterior (AP) bending. Then each femur was fatigued to 1000 cycles and tested to failure. Fourteen femurs were tested.

Results showed that axial stiffness values were not statistically different at different angles. AP bending stiffness of the high-angle (150°) construct was significantly higher than that of either of the other 2 constructs (for 2 screws only). Two-screw fixation appears to be adequate; adding a third screw may not be necessary.

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*Am J Orthop.* 2007;36(12):680-684.


Femoral neck fractures are an important problem in the United States, where an aging population has resulted in increased incidence.[1] Cannulated screw fixation of femoral neck fractures is often recommended for treatment of neck fracture.[2] The widely accepted technique is placement of 3 low-angle screws (typically 135°) in an inverted triangle position.[3-6]

Physiologic loading of the femoral head occurs at a 155° to 160° angle to the shaft of the femur.[7,8] For placement of a telescoping hip screw, a higher-angle placement (150°) provides a more rigid construct.[9-11] Although the primary objective of this study was to investigate the angle of screw placement, we also examined the difference between 2 and 3 screws, as 2 well-placed screws would provide adequate fixation.[12-15] A fourth screw does not substantially improve the construct.[4] Because 3 screws are customarily used, we subjected only those femurs that were fixed with 3 screws to more rigorous testing of cyclic fatigue.

## Materials and Methods

### Specimens

Eight matched pairs of macroscopically normal femurs were harvested from 8 cadavers, 5 males and 3 females (mean age, 74 years; range, 66-87 years). Two femurs were excluded from testing because of previous surgery (total hip prosthesis, hip screw). Fourteen fresh femurs (6 matched pairs, 2 unmatched femurs) were available for testing. After harvesting, all soft tissue was removed, and the femurs were frozen. To determine bone mineral density (BMD), we obtained dual-energy x-ray absorptiometry (DEXA) scans using the lunar machine (Prodigy Advance; GE Lunar, Madison, WI) at Overton Brooks Veterans Hospital in Shreveport, Louisiana. Before testing and fixation, each femur was thoroughly thawed. Based on 14 samples, SD of residuals (0.15), and difference of group means of 0.15 (repeated-measures analysis of variance [ANOVA]), the calculated power of our test would be 0.22.

### Fixation

Femurs were randomly assigned to fixation angles of 135°, 145°, and 150°. Guide pins were placed for 2 screws, using 3-point fixation, with 1 screw at the medial cortex and 1 at the posterior cortex. The pins were placed under fluoroscope with a standard angle guide. A cannulated drill was then used to make the screw holes. The pins (~1 mm in diameter) were then removed, and the necks were cut at a 70° angle to simulate a Pauwels type III fracture (Figure 1). Dr. Walker then replaced the pins with two 7.3-mm cannulated screws, and orientation was checked by x-ray. A small wedge was then cut from the medial cortex at the fracture line to simulate comminution—avoiding specimen-to-specimen variability in fracture generation. The femurs were then tested in axial and anteroposterior (AP) bending modes. A third

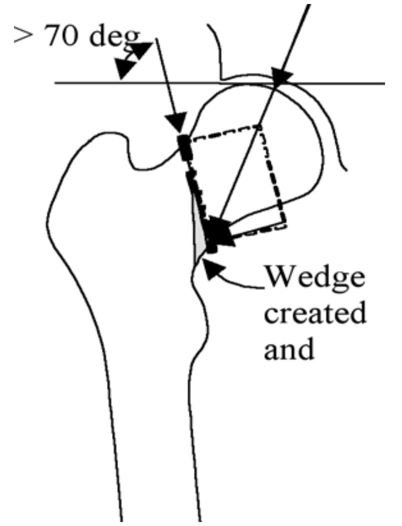


**Figure 1.** Simulation of Pauwels type III fracture.

**Figure 2.** Axial compression testing.

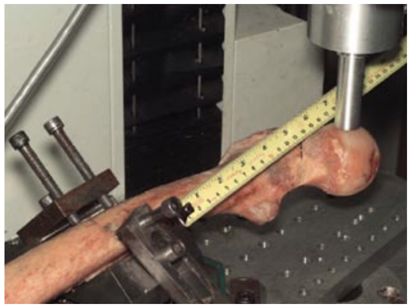

**Figure 3.** Testing in anteroposterior bending.

screw was then added to the fixation by the same technique to complete an inverted triangle. We could not randomize screw placement because the third screw had to be placed second, not first. If the third screw were inserted first, the extra hole would weaken the bone during testing of the 2-screw construct. The femurs were again tested in axial and AP bending modes and then fatigue-tested by cycling between 2 displacements by setting displacement controls within 2 limits. Last, each femur was axially loaded to failure.

### Mechanical Testing

Each bone was tested intact at the start of the experiment. Two separate jigs and testing machines were used for axial loading and AP bending. Axial loading was conducted in a biaxial servohydraulic testing machine (Instron 8874; Canton, MA; Figure 2). The axial loading jig held the femoral diaphysis at a 17° angle to the vertical to simulate the physiologic axial loading angle of joint reaction force during gait. Each femur was preloaded to 50 N, the crosshead was displaced 2 mm at 1 Hz, and testing was done for 5 cycles. AP bending was conducted in a uniaxial mechanical testing machine (Instron 4202; Canton, MA; Figure 3). Preload was not applied to the femoral head. With the AP bending jig, the femoral diaphysis was held perpendicular to the physiologic load to simulate rising from a seated position. For each femur, the AP bending load was applied 160 mm from the restraining contact point of the jig by displacing the crosshead of the testing frame to 1 mm at a rate of 25 mm per minute. Specimens for each testing mode were cycled to 5 cycles to reduce viscoelastic effects. Load-versus-displacement curves were generated for the fifth cycle in both axial and AP bending tests.

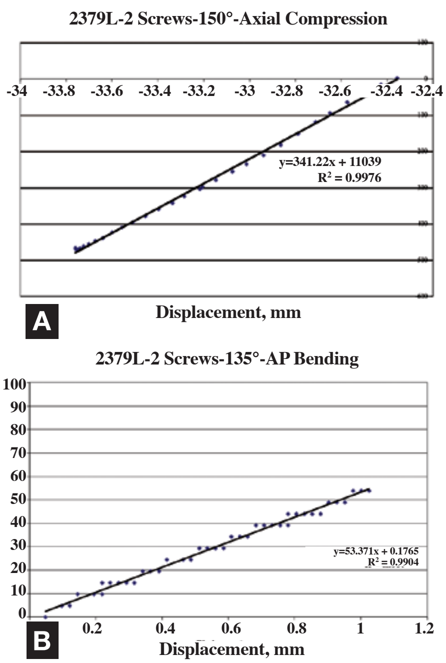


**Figure 4.** **(A)** Representative plot of load versus displacement (axial compression). **(B)** Representative plot of load versus displacement (anteroposterior bending).

### Statistical Analysis

Data were analyzed with repeated-measures ANOVA, and multiple pairwise between-subjects comparisons were made with the Student-Newman-Keuls method[16] to isolate

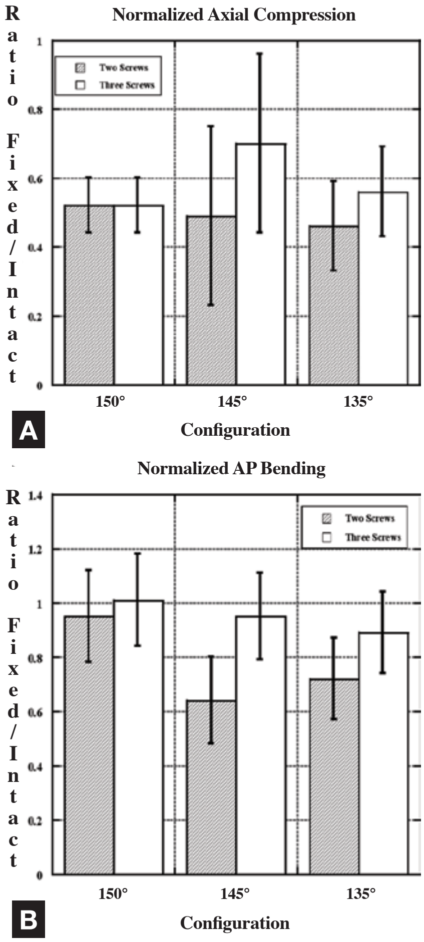


**Figure 5.** **(A)** Bar charts, axial compression. **(B)** Bar charts, anteroposterior bending.

the groups that differed significantly from each other using Sigma Stat software in a Gateway PC at the significance level of $P = .05$.

## Results

Tables I through III show results from axial compression and AP bending and failure properties after fatigue. Axial compressive stiffness values at 3 angles (150°, 145°, 135°) are shown in Table I; AP bending stiffness values at 3 angles (150°, 145°, 135°) are shown in Table II; failure data after cyclic fatigue (1000 cycles) are shown in Table III. In addition, representative load-versus-displacement plots are shown in Figures 4A and 4B, and normalized stiffness values (fixed/intact) are shown in Figures 5A and 5B.

These results did not show any statistically significant differences ($P = .05$ at power of .93) between the angles of screw placement for axial stiffness and 2 versus 3 screws. AP bending stiffness values at the high angle (150°) was highest among all the angles, showing a significant difference for 2 screws and not 3 screws ($P = .043$ and power of .49). There was no significant difference between 2 and 3 screws at each angle. BMD values of femurs did not differ significantly among the 3 groups (150°, 145°, 135°) at $P = .05$ and power of .05. However, when axial stiffness values for each group (135°, 145°, 150°) were correlated with their respective BMD, the regression coefficient was highest ($R^2 = .99$ for 2 screws and $R^2 = .77$ for 3 screws for 150°). $R^2$ values for all the angles are shown in Table IV. AP bending stiffness did not correlate with BMD ($R^2 < .02$).

## Discussion

The axial and bending stiffness values between the bones fixed at higher angle (150°) versus lower angle placement (145°, 135°) did not show any significant differences. Biomechanical analysis of joint reaction forces has shown that the resultant force acts at an angle of 155° to 160° to the biomechanical

**Table I.** Axial Compressive Stiffness (N/mm) at 3 Angles (150°, 145°, 135°)

| Specimen No. | BMD (g/cm²) | Intact | No. of Screws: 2 | No. of Screws: 3 | Ratio of Fixed Over Intact Stiffness Values: 2 Screws | 3 Screws |
|---|---|---|---|---|---|---|
| **150°** | | | | | | |
| 2369L | 0.66 | 649.8 | 377.0 | 295.1 | 0.58 | 0.45 |
| 2375L | 0.72 | 848.2 | 410.8 | 410.8 | 0.48 | 0.48 |
| 2379L | 0.60 | 799.2 | 341.2 | 347.4 | 0.43 | 0.43 |
| 2380L | 0.80 | 773.4 | 460.2 | 549.5 | 0.60 | 0.71 |
| Mean | 0.69 | 767.7 | 397.3 | 400.7 | 0.52 | 0.52 |
| SD | 0.09 | 84.5 | 50.7 | 109.9 | 0.08 | 0.13 |
| **145°** | | | | | | |
| 2365R | 0.75 | 964.6 | 577.4 | 584.0 | 0.60 | 0.61 |
| 2368R | 0.98 | 447.4 | 353.5 | 505.3 | 0.79 | 1.13 |
| 2380R | 0.83 | 669.9 | 252.6 | 416.3 | 0.38 | 0.62 |
| 2388L | 0.39 | 682.1 | 125.0 | 292.6 | 0.18 | 0.43 |
| Mean | 0.74 | 691.0 | 327.1 | 449.5 | 0.49 | 0.70 |
| SD | 0.25 | 211.9 | 191.3 | 125.0 | 0.26 | 0.30 |
| **135°** | | | | | | |
| 2364R | 0.44 | 533.7 | 320.4 | 436.9 | 0.60 | 0.82 |
| 2365L | 0.84 | 1663.2 | 896.6 | 1064.1 | 0.54 | 0.64 |
| 2368L | 1.07 | 797.7 | 335.9 | 387.1 | 0.42 | 0.49 |
| 2369R | 0.67 | 625.5 | 349.5 | 326.1 | 0.56 | 0.52 |
| 2375R | 0.75 | 941.3 | 259.2 | 417.8 | 0.28 | 0.44 |
| 2379R | 0.62 | 874.2 | 325.5 | 382.1 | 0.37 | 0.44 |
| Mean | 0.73 | 905.9 | 414.5 | 502.3 | 0.46 | 0.56 |
| SD | 0.21 | 401.2 | 238.2 | 277.8 | 0.13 | 0.15 |

**Table II.** Anteroposterior Bending Stiffness (N-m/mm) at 3 Angles (150°, 145°, 135°)

| Specimen No. | Intact | No. of Screws: 2 | No. of Screws: 3 | Ratio of Fixed Over Intact Stiffness Values: 2 Screws | 3 Screws |
|---|---|---|---|---|---|
| **150°** | | | | | |
| 2369L | 20.59 | 14.96 | 17.24 | 0.73 | 0.84 |
| 2375L | 15.03 | 14.91 | 14.00 | 0.99 | 0.93 |
| 2379L | 9.47 | 10.67 | 10.45 | 1.13 | 1.10 |
| 2380L | 15.62 | 15.17 | 18.11 | 0.97 | 1.16 |
| Mean | 15.18 | 13.93 | 14.95 | 0.95 | 1.01 |
| SD | 4.55 | 2.18 | 3.48 | 0.17 | 0.15 |
| **145°** | | | | | |
| 2365R | 23.31 | 16.22 | 21.29 | 0.70 | 0.91 |
| 2368R | 21.14 | 16.35 | 21.05 | 0.77 | 1.00 |
| 2380R | 15.61 | 10.95 | 15.65 | 0.70 | 1.00 |
| 2388L | 11.25 | 4.60 | 10.10 | 0.41 | 0.90 |
| Mean | 17.83 | 12.03 | 17.02 | 0.64 | 0.95 |
| SD | 5.45 | 5.55 | 5.30 | 0.16 | 0.05 |
| **135°** | | | | | |
| 2364R | 15.50 | 11.78 | 12.91 | 0.76 | 0.83 |
| 2365L | 27.55 | 16.87 | 15.57 | 0.61 | 0.56 |
| 2368L | 21.18 | 17.05 | 20.71 | 0.81 | 0.98 |
| 2369R | 19.85 | 12.98 | 15.18 | 0.65 | 0.76 |
| 2375R | 13.34 | 7.16 | 11.83 | 0.54 | 0.89 |
| 2379R | 8.93 | 8.54 | 11.73 | 0.96 | 1.31 |
| Mean | 17.72 | 12.40 | 14.66 | 0.72 | 0.89 |
| SD | 6.55 | 4.12 | 3.38 | 0.15 | 0.25 |

**Table III. Fatigue and Failure Data at 3 Angles (150°, 145°, 135°)**

| Specimen No. | Fatigue Data* (N/mm) | | Failure Data | |
|---|---|---|---|---|
| | 1 Cycle | 1000 Cycles | Load (N) | Slope* (N/mm) |
| **150°** | | | | |
| 2369L | 396.3 | 293.7 | 1507.7 | 290.0 |
| 2375L | 431.6 | 321.8 | 1780.4 | 172.1 |
| 2379L | 473.9 | 340.5 | 1481.9 | 490.5 |
| 2380L | 712.9 | 514.4 | 1830.0 | 566.5 |
| Mean | 503.7 | 367.6 | 1650.0 | 379.8 |
| SD | 143.0 | 99.7 | 180.7 | 181.0 |
| **145°** | | | | |
| 2365R | 759.0 | 666.6 | 2494.8 | 224.2 |
| 2368R | 623.9 | 464.3 | 2434.6 | 404.7 |
| 2380R | 436.6 | 312.9 | 1640.6 | 305.0 |
| 2388L | 260.9 | 180.6 | 1081.4 | 194.1 |
| Mean | 520.1 | 406.1 | 1912.9 | 282.0 |
| SD | 217.6 | 208.8 | 677.3 | 94.3 |
| **135°** | | | | |
| 2364R | NA | NA | NA | NA |
| 2365L | 1226.6 | 1079.9 | 3005.0 | 790.4 |
| 2368L | 564.0 | 362.9 | 1700.6 | 350.8 |
| 2369R | 421.6 | 291.9 | 1682.7 | 217.3 |
| 2375R | 354.1 | 222.4 | 1255.4 | 275.6 |
| 2379R | 425.5 | 196.7 | 1185.0 | 243.6 |
| Mean | 598.3 | 430.8 | 1765.8 | 375.6 |
| SD | 359.4 | 368.6 | 732.2 | 237.3 |

*Slope of load versus displacement.

**Table IV. Correlation of Bone Mineral Density and Axial Stiffness**

| Angle (°) | No. of Screws | Regression Equation | $R^2$ |
|---|---|---|---|
| 150 | 2 | 592.8 – 14.7 | .99 |
| | 3 | 1123.3 – 379.8 | .77 |
| 145 | 2 | 387.0x + 41.7 | .26 |
| | 3 | 354.1x + 188.4 | .50 |
| 135 | 2 | 281.6x + 208.5 | .06 |
| | 3 | 279.5x + 297.8 | .05 |

axis along the femur.[6-8] So, high-angle screw placement should have yielded higher stiffness values. One reason for the unexpected result may lie in the difficulty of screw placement at the specified angle, in spite of the fact that the pins were initially placed under fluoroscope. In addition, we tested a small number of cadaver specimens, and the highly variable data (caused by differences in cadaver bone properties) resulted in a larger SD. In an attempt to characterize bone properties, we used DEXA to measure intact-bone BMD; statistical analysis of the groups' BMD showed no significant differences. Individual axial and bending stiffness values were divided by their respective intact-bone values to reduce intraspecimen variability. Comparison of the 2- and 3-screw constructs showed a trend that axial stiffness of the fixated bone reached 70% of the intact value at 145° with 3 screws and 49% with 2 screws, but the difference was not statistically significant. Values at 150° and 135° were lower than values at 145°. While in AP bending at a high angle (150°), bending stiffness values approached those of the intact bone for 2 screws (95%) and 3 screws (100%). Both axial and bending stiffness values did not show significant improvement in stiffness as the number of screws was increased from 2 to 3. Placement of 2 screws—1 at the medial cortex of the femoral neck to the cortex of the femoral head and 1 at the posterior cortex of the femoral neck to the cortex of the femoral head—appears to provide adequate fixation. Placement of a third screw in the medial side may not be necessary.

Criticisms of this study are our use of the same bone for 2- and 3-screw fixations, simulation of fractures by sawing, absence of a predictive biomechanical model, and variations in femur size. Nevertheless, all operations and screw placements were performed by one person (Dr. Walker), avoiding operator-to-operator variability. Last, failure data (3 screws only) did not show any significant differences among angles.

This study had several limitations. The sample size was small, race and sex issues were not addressed, bone quality varied, and fractures were simulated by osteotomy. Although attempts were made to place the screws at specific angles by inserting guide pins under fluoroscope, it was difficult to visualize final screw placement. As this was a cadaver study, results need to be corroborated with clinical observations in living persons.

## Conclusions

The results showed several trends: (1) There was no difference in construct axial stiffness among screw-placement angles; (2) in AP bending, screw placement at 150° provided the most stiffness among all the tested constructs; (3) 2 screws provided adequate fixation, and no substantial advantage was seen in inserting a third screw; (4) failure data with 3 screws did not show any significant differences among screw-placement angles; and (5) axial stiffness at 150° was positively correlated with BMD but not with AP bending stiffness.

## Authors' Disclosure Statement

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

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