Optimizing Stability in Femoral Neck Fracture Fixation

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Femoral neck fractures are frequent orthopedic injuries with treatment and costs presenting a major public health problem. The optimal treatment, arthroplasty or internal fixation, is debated based on patient variables, fracture displacement, and fracture pattern. When proceeding with internal fixation, there are challenges in both young and old patients. The mechanical problems and strategies for achieving optimal stability are different in these 2 groups of patients.

Femoral neck fractures in younger adults usually result from high-energy trauma and have a vertical fracture pattern. Strategies for optimizing fixation stability in this group include placing additional screws at right angles to the fracture plane and medial buttress plate augmentation. In elderly patients, screw position relative to the intact cortical femoral neck bone is of critical importance. Additional strategies for optimizing fixation stability in this group include the concept of length stable fixation, use of adjunctive calcium phosphate cement, and use of novel fixed angle fixation implants. [Orthopedics. 2015; 38(10):625-630.]

Abstract: Optimizing stability of femoral neck fracture fixation is important in obtaining a successful outcome. The mechanical problems and strategies for achieving optimal stability differ depending on patients’ age and degree of osteoporosis. Femoral neck fractures in younger adults usually result from high-energy trauma and have a vertical fracture pattern. Strategies for optimizing fixation stability in this group include placing additional screws at right angles to the fracture plane and medial buttress plate augmentation. In elderly patients, screw position relative to the intact cortical femoral neck bone is of critical importance. Additional strategies for optimizing fixation stability in this group include the concept of length stable fixation, use of adjunctive calcium phosphate cement, and use of novel fixed angle fixation implants. [Orthopedics. 2015; 38(10):625-630.]

Anatomy and Biomechanics of the Femoral Neck

Although there is wide variability, the average femoral neck shaft angle measures 127° and the average femoral neck anteversion measures 13°. The primary blood supply to the femoral head is the deep branch of the medial femoral circumflex artery. It anastomoses anteriorly with branches of the lateral femoral circumflex artery and branches of the obturator artery. Additional anastomoses occur with the superior and inferior gluteal arteries, and internal pudendal artery.

Both gravity and hip abductor force vectors result in 2 dominant forces acting on the femoral neck. A force parallel to the long axis of the femur creates shear stress across the fracture plane. The other force...
lies parallel to the long axis of the femoral neck.6

Figure 1: Screw placed centrally in the osteoporotic femoral neck obtains purchase only at the cortex and subchondral bone, as shown in red (A). With axial force (arrow) placed across the hip, the fracture displaces until the screw shaft abuts the intact femoral neck cortex (B).

Cannulated screw fixation is a widely accepted technique for transcervical femoral neck fracture fixation because it is simple and minimally invasive. A number of biomechanical and clinical studies have attempted to identify the ideal configuration and number of screws for optimal fixation to resist axial, bending, and torsional forces passing across the hip joint. Fracture stability increases when increasing from 2 to 3 screws.10 The optimal construct for osteoporotic femoral neck fixation is an inverted triangle configuration with 3 parallel screws.11 The addition of a fourth screw has been shown to significantly increase construct strength in femoral neck fractures with significant posterior cortical comminution.12 Biomechanical studies and one clinical series have supported the use of washers, since screws inserted with washers generate significantly more compressive force.13,15 For basicervical femoral neck fractures, a sliding hip screw and a 6.5-mm cannulated derotation screw have been shown to be superior to the use of cannulated screws.16

**IMPORTANT OF SCREW POSITION IN FEMORAL NECK FIXATION**

Several studies have shown the critical importance of screw position relative to the femoral neck in resisting displacement and achieving union in femoral neck fixation. The central femoral neck area is devoid of bone, especially in older patients with progressive osteoporosis. Therefore, there is no resistance to displacement when screws are placed in this location. In elderly patients with osteoporosis, screws positioned centrally in the femoral neck have only 2 points of purchase: at the lateral cortex and in the subchondral bone of the femoral head. When a screw is placed in the central femoral neck area, displacement of the fracture will occur until the screw abuts the intact femoral neck cortex at the fracture site (Figure 1).

Each individual screw has a specific mechanical function that is based on its location, and should be positioned so as to achieve 3-point fixation with the third point of fixation being the intact cortical bone. The inferior screw should be positioned along the inferior cortex in the anteroposterior projection and centrally on the lateral projection to resist inferior displacement and varus collapse when the femoral head is loaded. The posterior screw is positioned along the posterior cortex and centrally on the anteroposterior image to resist posterior displacement and retroversion of the femoral neck. The final screw should be placed anteriorly on the lateral view and centrally on the anteroposterior view and essentially serves a tension band function by resisting retroversion of the femoral neck.

Lindequist et al17 have provided evidence about the importance of screw position relative to the femoral neck. In a cadaveric biomechanical study, they showed that a posterior screw position with cortical support increased the stability of the femoral neck fracture compared with a central screw position with only cancellous bone support.17 These findings are corroborated in another biomechanical study of simulated transcervical femoral neck fractures in a synthetic bone model that showed that screws abutting against the cortex were mechanically more stable than screws that were placed closer together in the center of the femoral neck.18

In two clinical studies, the position of the screws was carefully analyzed, and screws positioned within 3 mm of the femoral neck were defined as providing cortical support.19,20 Position of the screws in the femoral neck to provide cortical support resulted in improved union rates. Although screw position may not be critical in nondisplaced fractures, it appears critical for a successful outcome in displaced femoral neck fractures. In the later study, union occurred in 16 of 18 displaced femoral neck fractures in which
both screws were positioned to achieve cortical support. When only 1 of the screws was properly positioned to achieve cortical support, 13 of the 22 displaced fractures united, and when neither of the screws was properly positioned, none of the 5 displaced fractures united.20

**LENGTH STABLE FEMORAL NECK FIXATION**

Femoral neck shortening following femoral neck fracture fixation with cancellous screws is common and results in a significant negative impact on the patient’s physical function.21 In an observational study of 56 consecutive patients with united femoral neck fractures, 31% of non-displaced (14 of 45) and 27% of displaced (3 of 11) fractures shortened at the time of healing.22 The mean abductor moment arm shortening was 10±4 mm, and the mean femur length decreased by 8±5 mm. Twelve patients with nondisplaced fractures and 1 with a displaced fracture completed a Short Form-36 questionnaire. Patients with shortened fractures (8 of 13) had significantly lower physical functioning (P=.01) and role physical (P=.04) subscores.

Investigators studied a technique of internal fixation using nonsliding constructs to minimize femoral neck shortening. These constructs included a sliding hip screw or a dynamic helical blade with 2 fully threaded divergent screws placed into the head and neck, or 3 to 4 fully threaded cannulated screws. With this method, which first achieved sufficient reduction using various methods, they reported that 94% of patients successfully healed with minimal fracture site shortening.23

**NOVEL FIXED ANGLE FEMORAL NECK FIXATION IMPLANTS**

To address some of the disadvantages of cannulated screw fixation, investigators have developed a fixed angle device that combines the dynamic compression of a sliding hip screw and the anti-rotation advantages of the cannulated screws. The Targon femoral neck fixation system (Targon FN; Braun Melsungen AG, Melsungen, Germany) consists of a short 6-hole plate that incorporates 4 proximal dynamic locking cancellous screws with associated sleeves and 2 distal standard locking screws (Figure 2). The device is designed to allow controlled fracture collapse in line with the axis of the femoral neck, while the fixed angle implant design resists varus displacement.

The outcome of a consecutive series of 320 patients with nondisplaced and displaced femoral neck fractures treated with this device has been reported.24 There were 112 undisplaced fractures, of which 3 (2.7%) developed nonunion or re-displacement and 5 (4.5%) developed femoral head avascular necrosis. Conversion to an arthroplasty was required in 43 patients (20.7%), and 7 patients (3.3%) underwent elective hardware removal.

Another novel locking implant prototype designed for femoral neck fixation includes two 5.7-mm locking screws into the neck and head, one 4.5-mm lag screw into the calcar, and 2 locking screws into the shaft. Using a saw-bone vertical femoral neck model, investigators compared this prototype device with 3 parallel cannulated screws, a construct with 2 screws into the head and 1 transverse lag screw into the calcar, and a sliding hip screw with a dero-tation screw. The locking implant prototype had significantly increased axial stiffness compared with the other forms of fixation.25

**CEMENT AUGMENTATION**

In addition to novel developments in implant designs, new strategies that involve augmenting the femoral neck with polymethyl methacrylate or calcium phosphate cement have been described.26,27 The theoretical aim is to fill the porotic bony trabeculae with dense material in hopes of improving the pullout strength of implants and reducing cut outs and failures. In a biomechanical study published in 1997, calcium phosphate compared favorably with polymethyl methacrylate for augmentation of basivertical hip fractures in osteoporotic cadaveric hips.28 A more recently published systematic review highlighted a number of experimental and clinical studies that confirmed that both polymethyl methacrylate and calcium phosphate cements increased the primary stability of the implant/cement/bone construct.29 One promising novel implant for introduction of adjunctive augmentation materials is the N-Force cannulated screw (InnoVision, Inc, Memphis, Tennessee), which has a spiral hydraulic groove with radi-
ally spaced fenestrations that provide circumferential extrusion of augmentation materials around the implant. The unique design of this implant permits circumferential augmentation from the near cortex toward the head, shortening the working length of the screw and reinforcing the thin lateral cortex.

**VERTICAL SHEAR FEMORAL NECK FRACTURES**

Femoral neck fractures are rare in young patients and are usually a result of high-energy trauma. Pauwels classified femoral neck fractures based on the degree of verticality, with the higher grade category having a more vertical orientation (Figure 3). Pauwels’ grade III femoral neck fractures are usually caused by high-energy trauma, and are subjected to increased varus displacement moments leading to nonunion rates ranging from 16% to 59% and osteonecrosis rates ranging from 11% to 86%.

Factors in addition to the vertical orientation may also contribute to the high failure rate in Pauwels’ grade III fractures. Comminution at the inferior part of the femoral neck results in loss of the calcar’s inferomedial cortical buttress and may also contribute to the high failure rate. In a series of 33 patients with vertical shear femoral neck fractures, 96% of cases had major femoral neck comminution (1.5 cm in any dimension), which was mostly located inferiorly (94% of cases) and posteriorly (82% of cases). The average vertical fracture angle was 60° (range, 51°-80°). Investigators also examined the axial fracture angle measured on the axial computed tomography scan (Figure 2). Deformity in external rotation averaged 44° (range, 10°-68°) (Figure 4). Shortening of the femur averaged 1.8 cm (range, 0.9-4.4 cm).

**CURRENT FIXATION TRENDS**

A cross-sectional survey was administered to the Orthopedic Trauma Association’s active members to determine implant preferences in the surgical treatment of a vertical femoral neck fracture in a young adult patient. The preferred constructs for a vertical femoral neck fracture in a healthy young patient were a sliding hip screw with or without a derotation screw (47%), parallel cannulated screws with an off-axis screw (28%), and parallel cannulated screws (15%).

In addition to the standard triangle of 3 screws, surgeons have added an additional screw positioned perpendicular to the axis of the femoral shaft (Figure 5). This screw fulfills the principle of orienting a lag at right angles to the plane of the fracture. A biomechanical study of vertical femoral neck fractures showed that the addition of this transverse screw improved fixation stability.

**MEDIAL BUTTRESS PLATE AUGMENTATION**

To improve the fixation stability, Mir and Collinge hypothesized applying the concept of buttress to the treatment of vertical femoral neck fractures. A buttress plate placed in an anti-glide function can be applied antero-inferiorly over the fracture line and act to resist the shear forces seen in vertical femoral neck fractures. Mir and Collinge suggest using a modified Smith-Peterson approach for anatomical reduction. This approach can facilitate the reduction under direct visualization.
tion and also allow manipulation of the fracture fragment for exact anatomical reduction. In addition, the surgical approach can reduce the intracapsular hematoma that may contribute to the high pressure in the joint and induce avascular necrosis of the femoral head in the future. After the ideal reduction is obtained, a lateral approach can be used for primary fixation with either cannulated screws or a sliding hip screw. The medial buttress plate can be implanted through the anterior approach with the lower extremity in external rotation. To eliminate potential interference from the implant, the authors suggest the use of thin (1.7 to 2.7 mm thick) implants such as a third-tubular or mini-fragment plates (Figure 6).

A recent biomechanical analysis compared the strength of medial buttress augmented fixation with nonaugmented fixation techniques in vertical shear femoral neck fractures. 39 A vertical osteotomy model (Pauwel’s grade III) was created in fourth-generation composite femurs. Following reduction, specimens were fixed with either cannulated screws or a sliding hip screw implant. Half of each of the 2 types of fixation constructs were augmented with a medial buttress 2.7-mm locking plate. Both the cannulated screw and sliding hip screw constructs that were augmented with medial buttress fixation had significant higher stiffness and load to failure.

CONCLUSION
Femoral neck fractures are challenging fractures with a relatively high rate of failure. Strategies to prevent failures include adequate implant selection and adequate implant configuration with the addition of a buttress calcar plate when required in vertical neck fractures. An open approach to obtain anatomical reduction of the femoral neck in young patients may remain a critical step to improve patients’ outcomes and reduce failure rates. Clinical research on cement augmentation strategies must be conducted in the elderly to optimize the efficacy of such techniques, while clinical validation and longer follow-up of younger patients treated with medial buttress plates is necessary.

REFERENCES
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