Reducing Postoperative Fracture Displacement After Locked Plating of Proximal Humerus Fractures: Current Concepts

Authors:
Newman JM Kahn M Gruson KI
Author Affiliation | Disclosures

Jared M. Newman, MD, Mani Kahn, MD, and Konrad I. Gruson, MD

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Proximal humerus fractures account for 4% to 5% of all fractures.1 These fractures occur most frequently in the elderly—patients older than 60 years sustain 71% of these injuries2—and in females.1,3 Given an aging population, this incidence is predicted to increase 3-fold over the next 30 years.4 There is much debate regarding management of acute, displaced proximal humerus fractures. A recent Cochrane Review of published outcomes of operative and nonoperative treatment of displaced proximal humerus fractures found insufficient evidence supporting either modality, though surgery was associated with additional procedures.5 A review of 1000 proximal humerus fractures found that 49% had less than 1 cm of displacement of the major fragments or angulation of less than 45°.3 Other authors have reported similar findings.6,7 Although the incidence of proximal humerus fractures has remained stable over the past decade, from 1999 to 2005 there was a 25% relative increase in surgical management, including a relative increase of 29% in open reduction and internal fixation (ORIF) versus a 20% increase in arthroplasty.1

Locking plates have consistently demonstrated biomechanical superiority over other forms of fixation in osteoporotic bone.8,11 Egol and colleagues8 found that osteoporotic bone limited the torque of fixation to values less than what is required for adequate frictional force between the plate and the bone. This problem can be overcome with fixed-angle devices, such as locked plates.9 Compared with locked nail constructs, proximal humerus locking plates have demonstrated superiority in torsion, loading, and varus bending.10,11 Compared with blade plates, proximal humerus locking plates exhibited increased stiffness and torsional fatigue resistance.12 In a randomized clinical trial, Olerud and colleagues13 reported superior functional results with locking plate fixation compared with nonoperative treatment of displaced 3-part fractures in elderly patients with 2-year follow-up, though these clinical results were not supported by others.14 Two recent case-control studies comparing functional outcomes for 3- and 4-part fractures with follow-up of more than 2 years revealed higher Constant scores after locked plating compared with hemiarthroplasty, though complications were higher with locked plates.15,16 Adoption of locked proximal humerus plating has been correlated with good clinical outcomes and union rates, though this has been accompanied by a higher rate of reoperation.7 Reoperation rates from 1999 to 2005 increased both in the immediate postoperative period (odds ratio, 3.36) and at 1 year (odds ratio, 3.90).1
Complications of Locked Plating

Regardless of fixation type, reduced humeral head bone mass and quality may lead to implant loosening, fracture redisplacement, and, ultimately, poor outcomes. Baseline osteoporosis may predict likelihood of fixation failure.17 Multiple studies have reported on the implant-related complications associated with locking plate fixation—most commonly, intra-articular screw penetration, postoperative fracture displacement, and avascular necrosis (AVN)18-24 (Figure 1). A meta-analysis of 12 studies with a total of 514 proximal humerus fractures treated with locking plate fixation showed an overall complication rate of 49% and a 13.8% reoperation rate.25 The most common indication for reoperation involved intra-articular screw perforation. The most common complications were varus malunion (16%), osteonecrosis (10%), intra-articular screw penetration (8%), subacromial impingement (6%), and infection (4%).

Suboptimal intraoperative fracture reduction, specifically with residual varus, has been correlated with loss of fracture fixation. In a series of 153 fractures, loss of fixation occurred in 13.7% of cases, with the leading risk factor being varus malreduction.19 Failure rates were 30.4% and 11% when the head shaft angle was less than 120° and when it was 120° or more, respectively. Solberg and colleagues16 found that initial postoperative varus angulation of more than 20° resulted in universal loss of fixation. Conversion of these cases to hemiarthroplasty resulted in poor outcomes. Preoperative fracture alignment may also predict fixation failure.22 In one series, initial varus angulation healed with a mean 16° varus and a Constant score of 63, whereas initial valgus alignment healed with 6° varus and a Constant score of 71.22 Complications occurred in fractures that were initially in varus 79% of the time and initially in valgus 19% of the time. Screw perforation has been associated with loss of reduction 44% of the time.20
In an analysis of locking plate constructs revised after early (<4 weeks) failure in 8 patients with osteoporosis, Micic and colleagues found implant pullout leading to varus malalignment. All cases lacked medial support and subchondral screw purchase; 3 were initially malreduced. Owsley and Gorczyca retrospectively reviewed 53 cases of displaced proximal humerus fractures treated with locked plating. Despite the high rate of radiographic union, 36% developed complications, including screw cutout (23%), varus displacement of more than 10° (25%), and AVN (4%); 13% required revision. These complications disproportionately affected patients older than 60 years (57%) and negatively affected functional outcomes.

**Augmentation Techniques**

Despite its reported complications, proximal humerus locked plating remains the most widely used type of fixation. Advancements in locking plate design, improved understanding of fixation principles, and adoption of techniques augmenting proximal humerus locking plate fixation, particularly in osteoporotic bone, have reduced postoperative complications (Table 1).

**Rotator Cuff Sutures**

A widely adopted technique for neutralizing rotator cuff-deforming forces, which theoretically can cause fracture displacement, is incorporation of heavy nonabsorbable sutures. These sutures are placed through the rotator cuff-tuberosity junction and tied down after being passed through the plate. Obtaining and maintaining tuberosity reduction are essential in achieving good functional outcomes after fixation. In addition, tension band sutures may be particularly useful in the setting of initial varus deformity.
Although clinical use of these sutures is common, biomechanical studies of their adjunctive contribution to fracture stability are lacking.\textsuperscript{27} The rotator cuff musculature has a maximal contractile force of 3.5 kg/cm\textsuperscript{2}.\textsuperscript{28} Ricchetti and colleagues\textsuperscript{29} described a technique that involves using a locked plate and tagging the rotator cuff with heavy nonabsorbable sutures. Selective traction on the sutures can help obtain and maintain fracture reduction. Multiple studies have reported on suture use with locked plating for proximal humerus fractures.\textsuperscript{29-34} Badman and colleagues\textsuperscript{30} retrospectively reviewed 81 cases of metaphyseal defects or medial comminution treated with locked plating, rotator cuff sutures, and structural allograft. All cases healed within 6 months after surgery. The incidence of screw cutout was 3.7%, the incidence of AVN was 6.2%, and the incidence of varus collapse was 6%. A cadaveric study that used specimens (mean age, 77 years) with a simulated 3-part proximal humerus fracture treated with a locked plate both with and without cerclage sutures found no difference in interfragmentary motion between the groups.\textsuperscript{27} The authors concluded that additive sutures are not required for anatomically reduced fractures. Multiple sutures may counteract the deforming forces that act on bony segments that cannot be adequately maintained with screws, such as an osteoporotic greater tuberosity.

**Medial Column Restoration**

The importance of reducing and maintaining the medial calcar to provide biomechanical support for a laterally placed plate has been recognized.\textsuperscript{26,34-37} Gardner and colleagues\textsuperscript{26} suggested that medial support was achieved if the medial cortex was anatomically reduced, if the proximal fragment was impacted laterally onto the shaft, or if 1 or more inferomedial screws were placed. Cases that did not achieve medial support developed significantly more humeral head subsidence (5.8 mm vs 1.2 mm) and screw penetration. Krappinger and colleagues\textsuperscript{36} found that factors leading to fixation failure included age, local bone mineral density, anatomical reduction, and restoration of the medial cortical support. The authors concluded that anatomical reduction and restoration of the medial cortex were important in minimizing mechanical loads at the bone–implant interface. Biomechanically, Lescheid and colleagues\textsuperscript{37} found that the most stable construct was anatomical reduction with medial cortical contact. In the setting of comminution, however, it may be preferable to intentionally perform varus malreduction to achieve medial contact than to achieve anatomical reduction with a fracture gap. Badman and colleagues\textsuperscript{30} found that the incidence of screw penetration was 6% in patients with an intact medial calcar versus 29% in patients without medial support. In a retrospective analysis of patients treated with a locking plate and suture augmentation, Jung and colleagues\textsuperscript{35} concluded that restoring medial support was the most reliable factor in the prevention of loss of reduction with or without screw perforation. Last, Solberg and colleagues\textsuperscript{16} reported better clinical outcomes when the length of the metaphyseal segment attached to the articular fragment was more than 2 mm. A length of less than 2 mm was predictive of developing AVN.
Use of Bone Void Fillers

Allograft. Allograft is cancellous or corticocancellous chips or tricortical graft used as osteoconductive filler for metaphyseal defects.\(^{30}\) An increasingly popular technique involves using an endosteal fibular allograft strut to indirectly reduce the fracture and help support the medial calcar.\(^{38-42}\) Hettrich and colleagues\(^{40}\) reported on radiographic outcomes of displaced proximal humerus fractures with medial comminution treated with a locked plate and an endosteal fibular allograft or semitubular plate. The reduction was maintained in 96% of cases; there was 1 varus collapse. There were no cases of implant failure, screw perforation, or AVN. Other authors have also reported on successful use of fibular allograft in conjunction with a locked plate; the rate of reduction loss was low, and there were no cases of screw cutout or intra-articular screw penetration.\(^{38,41,42}\) These clinical outcomes are supported by results of biomechanical studies of the added benefit of intramedullary fibular allograft.\(^{43-46}\) Mathison and colleagues\(^{43}\) reported that a construct with fibular allograft and a locking plate increased the failure load by 1.72 times and the stiffness by 3.84 times compared with a control group of locking plate only. Bae and colleagues\(^{46}\) found significantly higher maximum failure load and construct stiffness with no varus collapse in specimens prepared with locked plate and fibular strut augmentation compared with a control group.

Others have successfully used cancellous allograft to fill humeral head bone defects.\(^{29,32,47-49}\) Duralde and Leddy\(^{47}\) reported 100% radiographic union and 81% good to excellent results in cases treated with a locking plate and morselized cancellous allograft to fill bone voids. Varus collapse and screw cutout did not occur, but there were 2 cases of AVN. Ricchetti and colleagues\(^{29}\) reviewed 54 cases treated with a locking plate and rotator cuff suture construct. Allograft cancellous chips and demineralized bone matrix were used in 3- and 4-part fractures (70% of cases) along with shorter screws in the humeral head. Major complications included AVN (1), fixation failure (3), and varus malunion (5). Others investigators have had less favorable results with use of cancellous bone graft. Schliemann and colleagues\(^{19}\) reported on 27 patients who were older than 65 years when they underwent ORIF with rotator cuff sutures to stabilize the tuberosities and either cancellous graft or a synthetic bone substitute in patients with massive metaphyseal defects. Patient-reported outcomes were superior to Constant scores. Complications included screw penetration (22.2%), reduction loss (44.4%), implant failure (3.7%), and AVN (29.6%).

Autograft. Autograft has both osteoconductive and osteoinductive properties and has been successfully used for metaphyseal defects.\(^{32,50}\) Kim and colleagues\(^{50}\) reported on patients with 4-part proximal humerus fractures treated with a locking plate and autologous iliac graft. All cases achieved union and had good or excellent outcomes. There were no cases of AVN, varus collapse, or hardware-related complications.

Bone Cement. Calcium phosphate cement has osteoconductive properties and enhances screw purchase in cancellous bone (Figures 2A-2F). It can be injected or molded into bone voids to provide improved compressive strength. It is resorbed through cell-mediated processes resembling bone remodeling and does not disappear until new bone forms. (Calcium sulfate cement, on the other hand, resorbs through a chemical process independent of new bone formation.\(^{51}\) ) Egol and colleagues\(^{52}\) reviewed the cases of 92 patients (mean age, 61 years) with 2-, 3-, and 4-part proximal humerus fractures treated with locked plate fixation. Metaphyseal defects were treated with no augmentation, augmentation with cancellous chips, or augmentation with calcium phosphate cement. Adding calcium phosphate cement was associated with lower incidence of intra-articular screw penetration and humeral head settling. In a recent cadaveric biomechanical study using 2-part proximal humerus fractures with metaphyseal comminution, the group augmented with calcium phosphate cement had enhanced axial stiffness and load to failure with reduced screw penetration.\(^{53}\) Other biomechanical studies have found increased screw pullout strength\(^{54}\) and decreased interfragmentary motion when specimens were augmented with calcium phosphate cement.\(^{55}\)
Similar good clinical and radiographic outcomes have been observed with use of calcium sulfate cement.\textsuperscript{56,57} Somasundaram and colleagues\textsuperscript{56} reported good clinical outcomes in 82\% of patients treated with locking plates and calcium sulfate cement used to fill metaphyseal voids. All fractures united without infection, fixation failure, subsequent malunion, tuberosity failure, or AVN. Lee and Shin\textsuperscript{57} compared outcomes of 14 patients who received calcium sulfate augmentation with outcomes of patients who did not receive this augmentation. Overall, 89\% of patients had good or excellent results. Calcium sulfate cement did not affect the reduction failure rate or clinical outcomes in cases in which medial cortical reduction was achieved. However, postoperative displacement caused by lack of medial support was associated with poor outcomes.

**Screw Placement**

Screws optimally should be placed in the posterior-medial-inferior aspect of the humeral head to provide medial support for the fracture and mechanical stability.\textsuperscript{58} Cadaveric studies have shown the highest cancellous bone density in the proximal, posterior, and medial portions of the humeral head.\textsuperscript{59-63} Similarly, in a cadaveric study, Liew and colleagues\textsuperscript{61} found greater screw purchase and higher pullout strength when the screw was placed in the center of the humeral head, within subchondral bone; fixation was poorest when the screw was placed in the anterosuperior region of the humeral head. Tingart and colleagues\textsuperscript{62} reported that humeral head trabecular density significantly affected pullout strength of cancellous screws. In addition, the most pullout strength was at the center of the head, and the least within the anterosuperior head. Trabecular density was higher in the inferior and posterior regions than in the superior and anterior regions.

Most locking plate designs allow screws to be placed at the level of the medial calcar—the goal being to provide medial column support (\textbf{Table 2}). Zhang and colleagues\textsuperscript{58} treated 2-, 3-, and 4-part fractures with a locking plate and randomized them into receiving the plate with or without medial support screws. For 3- and 4-part fractures, the group with these screws had a significantly greater final neck-shaft angle and smaller angulation loss compared with the group without screws. No additional benefit was found for 2-part fractures. Erhardt and colleagues\textsuperscript{63} simulated unstable proximal humerus fractures using cadavers and testing different fixation methods using a polyaxial locking plate. They found that 5 screws in the head fragment and an inferomedial support screw significantly reduced the risk of screw perforation. Other authors have concluded that placing 1 or more inferomedial screws is important in cases of medial comminution or medial column malreduction.\textsuperscript{59} Interestingly, compared with use of a polyaxial implant, which allows for adjustment of screw direction, use of a monoaxial locking plate did not lead to a clinically different outcome or complication profile.\textsuperscript{64}
Techniques have been used to achieve subchondral purchase of locking screws while reducing iatrogenic articular perforation. However, given the incidence of fracture settling and subsequent postoperative screw penetration, many authors currently recommend using shorter divergent screws combined with other augmentation techniques, described previously.

**Physical Therapy**

There is no standardized physiotherapy regimen for postoperative management of proximal humerus fractures treated with locking plates. In older patients, immediate active range of motion (ROM) exercises should be delayed until early callus is noted, though there is a risk for stiffness. Lee and Shin found that a delay in rehabilitation after ORIF was an independent risk for poor clinical outcome. Namdari and colleagues recommended sling use only for comfort and initiated non-load-bearing activities and pendulum exercises immediately after surgery. Patients with adequate reduction at 4 to 6 weeks were advanced to full weight-bearing. Badman and colleagues initiated passive-assisted ROM exercises when the wound was healed at 2 weeks in 2-part fractures, whereas patients with 3- and 4-part fractures were immobilized until radiographic healing. Formal therapy was started after 6 weeks. Stiffness was reported in 5% of patients. For patients with stable fixation, Ricchetti and colleagues recommended passive shoulder ROM exercises on postoperative day 1; at 4 to 6 weeks, patients should start active shoulder ROM exercises, and then resistance exercises at 10 to 12 weeks. Other authors are more conservative—only sling immobilization and pendulum exercises the first month. Barlow and colleagues immobilized their patients (age, >75 years) for 6 weeks. No patient developed disabling stiffness. The authors suggested that patients older than 75 years may not be prone to stiffness.

**Our Preferred Treatment Method**

All proximal humerus fractures are approached anteriorly through the deltopectoral interval (Figure 3A). The long head biceps is identified and truncated for later tenodesis. Multiple No. 5 Ethibond sutures (Ethicon) are placed at the bone–tendon interface. The fracture is reduced with a Cobb elevator (Figure 3B), and provisional Kirschner wires are placed within the head (Figure 3C). The plate is affixed to the humeral head with its anterior border paralleling the posterior aspect of the bicipital groove. Multiple locking screws are placed within the
superior and posterior humeral head. Nonlocking screws are then used to fix the plate to the shaft to reduce the specific deformity. Under fluoroscopy, any metaphyseal void is filled with calcium phosphate cement (Figure 3D). The remaining inferior screws are placed within the humeral head. Dr. Gruson uses screws 4 to 6 mm short of subchondral bone to reduce the risk for joint penetration. The rotator cuff sutures are tied down through the plate. Patients are started on progressive supine passive ROM exercises at 7 days, followed by supine active-assisted ROM exercises 6 weeks after fracture healing is confirmed radiographically.

Conclusion

Use of locked plating for proximal humerus fractures has increased, particularly in the elderly. Resulting complications include intra-articular screw penetration, postoperative fracture displacement, and AVN. Recognition of the importance of reducing and supporting the medial calcar, filling any metaphyseal defects, and selectively placing screws within the humeral head has lowered the incidence of these complications. Further comparative studies evaluating the efficacy of individual augmentation techniques are needed to determine their contribution to successful fracture healing and their cost-effectiveness. Results of such studies may help in the development of protocols for more standardized implementation of these techniques and in understanding which specific fracture patterns and patients would benefit from their use.

Key Info

Figures/Tables
References


**Multimedia**

**Product Guide**

**Product Guide**

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- BioComposite SwiveLock C, with White/Black TigerTape™ Loop
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