Second-Generation Concepts for Locked Plating of Proximal Humerus Fractures

Abstract
Displaced fractures of the proximal humerus remain particularly difficult to treat. Because of the poor quality of cancellous bone, it seemed that locking plates would be ideally suited for fixation in this region. However, as clinical reports begin to become available, it appears that these plates are not a panacea for these fractures and may be associated with a high complication rate. Coupled with the generally poor long-term outcomes of hemiarthroplasty, new fixation methods must be sought. Several technical factors, techniques, and alternative approaches have recently been described as possibly improving fixation stability in these fractures. Specifically, the anterolateral acromial approach, which avoids vascularity exposure, allows direct access to the lateral plating zone, and minimizes soft-tissue dissection, may be useful. Mechanical support of the medial column when anatomic cortical contact is not possible is also critical to maximizing stability. This may be achieved either with purposeful inferomedial humeral head screws or endosteal fibula allograft augmentation.

Historical Perspective
Fractures of the proximal humerus most often present with a stable, minimally displaced fracture pattern. In these cases, sling immobilization and early rehabilitation lead to predictable healing and functional outcomes. However, when one or several fragments are displaced in an unstable configuration, surgical intervention should be considered.

Several techniques have been used for surgical fixation, including suture tension banding, percutaneous pinning, intramedullary nailing, and plating. Obtaining stable fixation within the humeral head has historically been difficult because of several factors. First, many musculotendinous units insert on the proximal humeral head and shaft, which impart significant deforming forces across the fractures. This can vary depending on associated fractures of the greater or lesser tuberosity. The pectoralis major tends to displace the humeral shaft medially. Second, many fractures occur after low-energy traumatic mechanisms in elderly patients with significant osteopenia (Figure 1). With increasing age, overall bone mass decreases, and trabecular connectivity and thickness decrease.

Dr. Gardner is Fellow, Orthopaedic Trauma, Harborview Medical Center, Seattle, Washington. He was a Resident, Orthopaedic Trauma Service, Hospital for Special Surgery/New York Presbyterian Hospital, New York, New York, at the time the article was written.
Dr. Lorich is Attending, Orthopaedic Trauma Service, Hospital for Special Surgery/New York Presbyterian Hospital, New York, New York.
Dr. Werner is Attending, Department of Orthopaedic Surgery, University of Zurich, Balgrist, Zurich, Switzerland.
Dr. Helfet is Director, Orthopaedic Trauma Service, Hospital for Special Surgery and New York Presbyterian Hospital, New York, New York, and Professor, Orthopaedic Surgery, Weill Cornell University Medical College, New York, New York.

Requests for reprints: Michael J. Gardner, MD, Harborview Medical Center, 325 9th Ave, Seattle, WA 98105 (tel, 206-731-3267; fax, 206-731-3227; e-mail, michaelgardnermd@gmail.com).

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phenomenon that is pronounced in the humeral head.\(^1\) The generalized poor bone quality in the humeral head in these patients has direct implications for anchoring screws for fracture stabilization, and age is the most important predictive variable for successful fixation.\(^4,5\)

Traditional compression plating has not led to reliable fixation in osteoporotic displaced proximal humeral fractures.\(^6-10\) Results are unsatisfactory in up to 80% of patients with multifragmentary fractures.\(^7\) Sturzenegger and colleagues\(^8\) found a 3-fold risk of avascular necrosis (AVN) after open buttress plating of proximal humerus fractures. Other authors have corroborated the high AVN rate and fixation failure with traditional open reduction and internal fixation (ORIF) and have recommended percutaneous pinning or other minimally invasive techniques for 3-part fractures and nonoperative, minimally invasive, or prosthetic treatment for 4-part fractures.\(^11-15\)

Unfortunately, for these difficult fractures, hemiarthroplasty has not produced reliably good outcomes either. Zyto and colleagues\(^16\) found that mean flexion and abduction were 70°, and 33% of patients had moderate to severe pain and disability. Goldman and colleagues\(^17\) reported that mean flexion was 107°, that one fourth of patients had at least moderate pain, and that 73% had substantial functional deficits. In patients younger than 50 years, incidence of glenoid erosion is high, and, in a large series of atraumatic shoulder pathology cases, almost 50% of patients had unsatisfactory results.\(^18\) Results from these studies and others imply that hemiarthroplasty may not be an ideal long-term solution for patients with high functional demands. We believe that elderly patients with 4-part fractures with a head-splitting component, poor bone quality, or traumatic vascular damage are ideal candidates for primary hemiarthroplasty. Otherwise, recently improved understanding of the necessary components of successful locked plating, development of soft-tissue-sparing approaches, and poor results with hemiarthroplasty make humeral head replacement not advisable in the majority of patients.

### Table. Pros and Cons of the Deltopectoral Approach and the Anterolateral Acromial Approach

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<th>Deltopectoral Approach</th>
<th>Anterolateral Acromial Approach</th>
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<tr>
<td>Pros</td>
<td>Cons</td>
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<tr>
<td>- Familiar to orthopedic surgeons</td>
<td>- Requires substantial retraction and often release of deltoid</td>
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<tr>
<td>- Extensile distally</td>
<td>- Humeral head blood supply in dissection field</td>
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<td>- Easy conversion to hemiarthroplasty</td>
<td>- Difficulty reducing greater tuberosity fragment</td>
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<td>- Difficulty obtaining lateral to medial vector for locking drill guides for distal locking screws</td>
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<td>- Unfamiliar to trauma surgeons</td>
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<td>- Axillary nerve at risk</td>
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<td>- Difficult, but possible, to convert to hemiarthroplasty</td>
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First-Generation Locked Plating

The advent of locked plating has shown the potential to achieve more stable fixation in osteoporotic bone because of the fixed angle established at the plate–screw interface.\(^19,20\) Despite frequent use of these devices in recent years, guidelines for critical reduction parameters and implant position to create a biomechanically sound construct have not been fully elucidated. As a result, preliminary outcomes studies using locked plates have resulted in a significant number of mechanical failures.

Bjorkenheim and colleagues\(^21\) reported a 26% incidence of varus deformity. Fankhauser and colleagues\(^22\) found an 11% incidence of fixation failure, with frequent screw penetration of the articular surface. A preliminary report of a multicenter study of 132 patients found a 9% rate of fixation loss and a 20% revision rate, and 23% of cases were considered failures at 1 year.\(^23\) Frangen and colleagues\(^24\) demonstrated a 22% failure rate of the locked plate construct in 166 patients. Similarly, Owsley and Gorczyca\(^25\) reported that 20% of the 75 patients in their series failed in varus, and 17% had hardware cutout of the humeral head.

Despite these early suboptimal results with locking implants, several factors and modifications have been identified as possibly improving on initial fixation stability. Specifically, more direct surgical approaches may minimize muscle retraction and vascular damage. In addition, attention to reduction of the medial cortex, directed implant placement, and endosteal augmentation of the medial column and humeral head may help maintain the reduction until fracture healing occurs.

Surgical Approaches

The traditional workhorse approach to the proximal humerus is through the deltopectoral interval. However, several disadvantages are associated with this approach when used for ORIF of proximal humerus fractures (Table). Most important, this interval is anterior to the shoulder joint. Placing screws through a locked plate...
does not allow variation in screw angle insertion, and threaded guides are screwed to the plate to establish the correct angle for drilling and screw placement. An anterior approach requires substantial retraction of the deltid muscle mass and internal rotation of the humerus for lateral access. Techniques such as partial release of the deltid insertion may be used to overcome this, but the deltid insertion is only 40% of the circumference of the humerus, and even minimal release of the deltid insertion can lead to functional deficits.

### Anterolateral Approaches

The anterolateral acromial approach is a direct surgical approach to the plating region of the lateral proximal humerus. The skin is incised from the anterolateral corner of the acromion distally, and the anterior deltoid raphe, between the anterior and middle deltoid heads, is developed (Figure 2). The axillary nerve is found approximately 6 cm from the acromion and 3.5 cm from the prominence of the greater tuberosity if it is intact. With the nerve protected, reduction of the fracture can proceed, working through the fracture lines to protect the tenuous blood supply. The locked plate can be slid distally under the nerve under direct visualization after reduction is achieved (Figure 3). No iatrogenic axillary nerve injuries have occurred in more than 70 cases performed using this approach, and in several cases the nerve was found to be incarcerated in the fracture and freed before fracture reduction.

Laflamme and colleagues, who used a proximal deltoid-split approach for locked plating of 30 proximal humerus fractures, noted that the axillary nerve was easily palpated and protected in all cases. Similarly, Lill and colleagues, who used a deltoid-splitting approach emphasizing vigilant protection of the axillary nerve, performed fracture reduction and locked plating without complication. Finally, Robinson and Page advocated a strap incision, also with protection of the axillary nerve. They used a laterally based approach to facilitate reduction and encountered no related nerve injuries. These approaches have been based on well-described anatomical data and may minimize soft-tissue dissection and facilitate appropriate implant placement during fracture treatment.

### Vascular Considerations

Vascularity is also a critical consideration in the treatment and outcomes of proximal humerus fractures. The vascular supply around the proximal humerus has been the subject of much research. Gerber and colleagues, who conducted a perfusion study of the humeral head, demonstrated that the arcuate artery, a branch of the anterior humeral circumflex system, was critical for perfusion of the majority of the humeral head. These authors emphasized that this branch must be preserved during surgical approaches, and they noted that many techniques of internal fixation are likely to injure this vascular supply (Figure 4). Other investigators have reported that the posteroomedial vascular plexus may also play an important role in reperfusion of the humeral head after a displaced fracture. Hertel and colleagues correlated length of medial metaphy-

**Figure 2.** In the anterolateral acromial approach, the raphe between the anterior and middle heads of the deltid is developed. Reprinted from *J Orthop Trauma*, vol. 20, Gardner MJ, Voos JE, Wanich T, Helfet DL, Lorich DG, Vascular implications of minimally invasive plating of proximal humerus fractures, pages 602-607, copyright 2006, with permission from Lippincott Williams & Wilkins.

**Figure 3.** With the axillary nerve protected, the plate can be slid deep to the nerve. Reprinted from *J Orthop Trauma*, vol. 20, Gardner MJ, Voos JE, Wanich T, Helfet DL, Lorich DG, Vascular implications of minimally invasive plating of proximal humerus fractures, pages 602-607, copyright 2006, with permission from Lippincott Williams & Wilkins.

**Figure 4.** The anterior humeral circumflex provides the vascular supply to a large portion of the humeral head and is directly in the plane of dissection during a deltopectoral approach. Reprinted from *J Orthop Trauma*, vol. 20, Gardner MJ, Voos JE, Wanich T, Helfet DL, Lorich DG, Vascular implications of minimally invasive plating of proximal humerus fractures, pages 602-607, copyright 2006, with permission from Lippincott Williams & Wilkins.
seal extension and medial displacement with risk for AVN, which suggests that the posteromedial vessels play a major role in perfusion. Although the critical vascularity to the humeral head may vary according to fracture pattern and displacement, surgical interventions should minimize dissection medial to the bicapital groove to preserve the potentially tenuous anterior blood supply. The anterolateral acromial approach allows direct access to the lateral “bare spot” on the proximal humerus, which is between the arcurate artery and a vessel that dives intraosseously at the posterior border of the greater tuberosity (Figure 5). These lateral approaches, which avoid exposure and dissection in the region of the anterior vascular system, may cause less iatrogenic vascular injury and minimize incidence of AVN. In high-risk cases, with medial comminution and displacement and with traumatic soft-tissue stripping, augmenting fracture healing with demineralized bone matrix or bone morphogenetic protein (BMP) locally, or parathyroid hormone systemically, may prove to be useful.

**Medial Column Stabilization**

Placement of a locking plate on the lateral cortex of the proximal humerus establishes a mechanical construct that functions as a tension band. As the rotator cuff fires and attempts to deform the humeral head in varus, these forces may be converted to medial compression forces, essentially offloading the implant and creating a load-sharing construct between the implant and the bone. Mechanical stability of the construct, however, relies on an intact and apposed medial cortex that is functionally able to transmit load. For this reason, Gerber and colleagues emphasized the importance of achieving an anatomical reduction of the medial cortex in achieving a successful outcome with plate fixation. Other studies have shown, in fractures treated with locking plates without mechanical support of the medial cortex, a high incidence of loss of fixation with varus malalignment and hardware cutout.

Unfortunately, in many of the fractures that occur after high-energy mechanisms or in osteoporotic bone, significant comminution of the medial column is present. When the medial cortex is either malreduced or comminuted, it is unable to share load with the implant, and high stresses occur at the locking screws in the humeral head. In this situation, a lateral locked plate may be unable to neutralize the deforming forces of the proximal fragment, in either young or older patients. In these situations, there are several technical options for creating a mechanically favorable construct. First, the shaft may be medialized, effectively impacting the proximal humeral head fragment laterally in the shaft. Although this creates deformity in several planes, an element of stability is likely to be conferred. All attempts should be made to anatomically reduce the medial cortex, or to medialize the shaft if necessary.

When initial medial displacement of the humeral head fragment is present and associated with comminution, reduction can be difficult. Regardless of the reduction achieved, it appears that placement of locking screws in the inferomedial quadrant of the humeral head, to within 5 mm of the subchondral bone, imparts a substantial mechanical advantage. In a series of patients with proximal humerus fractures who had medial comminution and malreduction of the medial cortex, screws placed inferomedially minimized subsequent reduction loss and implant cutout (Figure 6). The basis for screw placement in this region is supported by histomorphometric studies, which have reported particularly poor bone quality in the superior regions of the humeral head.

It is important to consider that the vascular anatomy around the medial surgical neck of the humerus particularly the posteromedial vascular tree, is also important for humeral head perfusion. Direct exposure or implant placement medially is contraindicated, so only indirect reduction techniques of the medial column are possible. The anterolateral approach may be particularly...
ful healing occurred with a maintained reduction at 10 weeks allowing it to maintain the medial reduction and provide additional mechanical support. Additional locking screws are placed inferomedially, creating a stable construct. In this case, uneventful healing occurred with a maintained reduction at 10 weeks.

Figure 7. A segment of fibular allograft is inserted through the lateral fracture lines (A) to the appropriate depth. The locking plate is placed laterally over the reduced tuberosities (B), and a push screw is used to translate the fibula medially, indirectly reducing the medial cortex (C). The fibula is locked in place, allowing it to maintain the medial reduction and provide additional mechanical support. Additional locking screws are placed inferomedially, creating a stable construct. In this case, uneventful healing occurred with a maintained reduction at 10 weeks (D).

suited for this purpose, as the lateral exposure goes directly to the intertuberosity fracture line, allowing the surgeon to work within the fracture lines to indirectly reduce the medial column.

Besides reduction of the medial cortex, several factors are critical to maximizing outcome. Anatomical reduction of the tuberosities, followed by secure fixation with heavy nonabsorbable sutures through the rotator cuff, cannot be overemphasized. Newer implants have holes on the borders of the plate head specifically for assisting in anchoring the tuberosities. Finally, height of the humeral head fragment should be restored relative to the tuberosities and humeral shaft. This maintains a lever arm for the rotator cuff mechanism to work efficiently, minimizes risk for subacromial impingement, and reverses any residual varus deformity of the humeral head reduction.

**Endosteal Implants**

Because the cancellous bone in the humeral head may be extremely brittle and not amenable to stable screw anchorage, techniques using endosteal implants have been developed on the basis of techniques popularized by Mast and colleagues. Implants placed endosteally have the advantage of being able to assist both in indirect reduction of the medial column and in providing mechanical support for the medial column and humeral head fragment. These functions may be used in combination or individually, depending on the needs of the fracture. Small fragment plates may be used in this role, but we have found that a short segment of fibula allograft is extremely effective for this purpose.

The neurovascular anatomy around the medial proximal humerus precludes direct approaches to this region. As already mentioned, medial reduction is critical, and indirect methods are often needed to achieve reduction. When the humeral head fragment remains medial and in varus malalignment after indirect reduction techniques, a fibular allograft segment approximately 6 cm long can be used for reduction and reconstruction of the medial cortex. The fibula is inserted into the humeral shaft through the lateral fracture lines and positioned such that several centimeters lie above the surgical neck. The tuberosities are reduced, and the plate is placed laterally. One or several push screws are used to translate the fibula medially, allowing precise positioning of the shaft fragment relative to the proximal fragment. The fibula, which is then locked into place with several screws, subsequently augments cortical support of the medial column (Figure 7).

An endosteal fibula allograft may alternatively be used as an oblique strut to “prop up” the humeral head fragment—alogous to fibular strut grafting used for mechanical support in osteonecrosis of the hip, originally described by Phemister. This application is most useful in varus impacted fractures. Kirschner wires should be placed from the shaft fragment into the infero humeral head as a stable platform on which to leverage the fibular allograft under the head (Figure 8). The proximal fibula may be cut at an oblique angle parallel to the fracture surface of the humeral head fragment. The fibula can then be incorporated into the locking construct to contribute mechanical support. Other authors have reported the necessity of using allograft materials to provide support and subsequent good results in these fractures.

Allograft fibula strut graft is ideal for use in proximal humerus fractures because of its dimensions and initial strength. We have used fibula allografts in 7 proximal humerus fractures and have had no reduction loss or implant failure. In our clinical experience, the cortical edges of the fibula become blunted, and the allograft appears to incorporate into the host bone by 6 to 12 weeks. Drawbacks to using a fibula—similar to those of any allograft tissue—include risk for infection and relatively limited availability. Given the high rate of hardware complications with standard techniques of proximal humerus locked plating, we believe that mechanical augmentation of the medial column with a fibula may offset the cost of a high reoperation rate. Alternatively, however, endosteal plates may be used to confer additional medial column support.

Figure 8. In the case of varus impaction of the humeral head, a shorter fibular allograft can be leveraged off Kirschner wires to assist in reduction and to function as a mechanical prop to the head fragment.
Summary

Displaced proximal humerus fractures present difficult challenges in establishing stable fixation. Unique to these fractures are the tenuous blood supply, the proximity of critical neurovascular structures to the surgical intervals, and the poor quality of bone available for fixation. Locked plates have provided an important initial step in improving initial fracture fixation stability. When used incorrectly, however, these devices do not appear to be a panacea in treating these fractures. Newer concepts in treating proximal humerus fractures with these devices may improve on early fixation failures. More direct surgical approaches that minimize soft-tissue stripping and vascular damage may improve fracture healing potential. Recognition of the importance of the integrity of the medial column, as well as screw placement in the inferomedial humeral head, appears to be a major factor in the resulting mechanical stability. Finally, endosteal implants, particularly fibular allografts, may be useful as reduction tools and can be locked into place to provide additional support in difficult fractures with medial comminution. Further refinement of these and other techniques, with correlation to maintenance of reduction and functional outcomes, will be critical to develop reliable methods of fracture stabilization.

Authors' Disclosure Statement

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

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11. Gardner MJ, Weil Y, Barker JU, Kelly BT, Helfet DL, Lorich DG. The importance of the integrity of the medial column, as well as screw placement in the inferomedial humeral head, appears to be a major factor in the resulting mechanical stability. Finally, endosteal implants, particularly fibular allografts, may be useful as reduction tools and can be locked into place to provide additional support in difficult fractures with medial comminution. Further refinement of these and other techniques, with correlation to maintenance of reduction and functional outcomes, will be critical to develop reliable methods of fracture stabilization.

This paper will be judged for the Resident Writer's Award.