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# Management of Proximal Humeral Fractures Based on Current Literature

By Shane J. Nho, MD, MS, Robert H. Brophy, MD,  
Joseph U. Barker, MD, Charles N. Cornell, MD, and John D. MacGillivray, MD

## Introduction

Proximal humeral fractures are the second most common upper-extremity fracture and the third most common fracture, after hip fractures and distal radial fractures, in patients who are older than sixty-five years of age<sup>1</sup>. Although the overwhelming majority of proximal humeral fractures are either nondisplaced or minimally displaced and can be treated with sling immobilization and physical therapy, approximately 20% of displaced proximal humeral fractures may benefit from operative treatment. Many surgical techniques have been described, but no single approach is considered to be the standard of care. Surgeons who treat proximal humeral fractures should be able to identify the fracture pattern and select an appropriate treatment on the basis of this pattern and the underlying quality of the bone. Orthopaedic surgeons should have experience with a broad range of techniques, including transosseous suture fixation, closed reduction and percutaneous fixation, open reduction and internal fixation with conventional and locked-plate fixation, and hemiarthroplasty. In the future, locked-plate technology and the use of osteobiologics may play an increasingly important role in the treatment of displaced proximal humeral fractures, facilitating preservation of the humeral head in appropriately selected patients.

The goals of this article are to enable the reader to: (1) become familiar with the recent literature on the classification of and treatment options for proximal humeral fractures, and (2) better identify fracture characteristics and devise an appropriate treatment plan.

## Treatment Options

### *Transosseous Suture Fixation*

#### *Surgical Technique*

Park et al.<sup>2</sup> described different operative approaches for each fracture pattern described by Neer<sup>3</sup>. For two-part

greater tuberosity fractures, an anterosuperior approach along the Langer lines extending from the lateral aspect of the acromion toward the lateral tip of the coracoid is used. The split occurs in the anterolateral raphe and allows exposure of the displaced greater tuberosity fracture. When a surgical neck fracture exists, Park et al.<sup>2</sup> prefer a standard deltopectoral approach. Nonabsorbable suture is used to capture rotator cuff tissue anteriorly, laterally, and posteriorly to the fragment. The displaced humeral head is reduced and fixed to the shaft through drill holes or suture anchors. Three-part fractures involving the greater tuberosity and the surgical neck can be repaired by initially bringing the head to the shaft, followed by reduction and fixation of the greater tuberosity. Flatow et al.<sup>4</sup> described an anterosuperior approach and the use of heavy nonabsorbable sutures for greater tuberosity fractures (Fig. 1).

#### *Indications*

Transosseous suture fixation has been described as a treatment option for proximal humeral fractures that have at least 1 cm of displacement between the head and the shaft fragments or 5 mm of displacement of the tuberosity fragment. The proponents of this technique emphasize the advantage of avoiding the risks associated with hardware, which include pain, neurovascular compromise, migration, failure, and the need for removal. The underlying rotator cuff musculature can be used as a means to realign the fractures and enhance stability. Furthermore, the long-term functional recovery of the rotator cuff is a key component of overall patient outcome.

#### *Contraindications*

Contraindications to this approach include previous attempt(s) at internal fixation or fractures older than six weeks. Also, the use of this technique for highly comminuted four-part fractures is not recommended.

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## Results

Flatow et al.<sup>4</sup> reported that all twelve patients who had transosseous suture fixation of an isolated greater tuberosity fracture had good or excellent results with osseous union. Park et al.<sup>2</sup>, in a review of twenty-eight shoulders with two-part greater tuberosity, two-part surgical neck, and three-part greater tuberosity and surgical neck fractures that were treated with transosseous suture fixation, reported that 78% of the patients had an excellent result according to the criteria of Neer et al.<sup>5</sup> and that there was no difference between the results obtained with two-part greater tuberosity fractures and those obtained with two-part surgical neck or three-part fractures. Panagopoulos et al.<sup>6</sup> used transosseous suture fixation for four-part valgus-impacted proximal humeral fractures, and the mean Constant-Murley score<sup>7</sup> for the operative shoulder was 87 compared with 94 for the contralateral shoulder. Partial osteonecrosis of the humeral head developed in one patient.

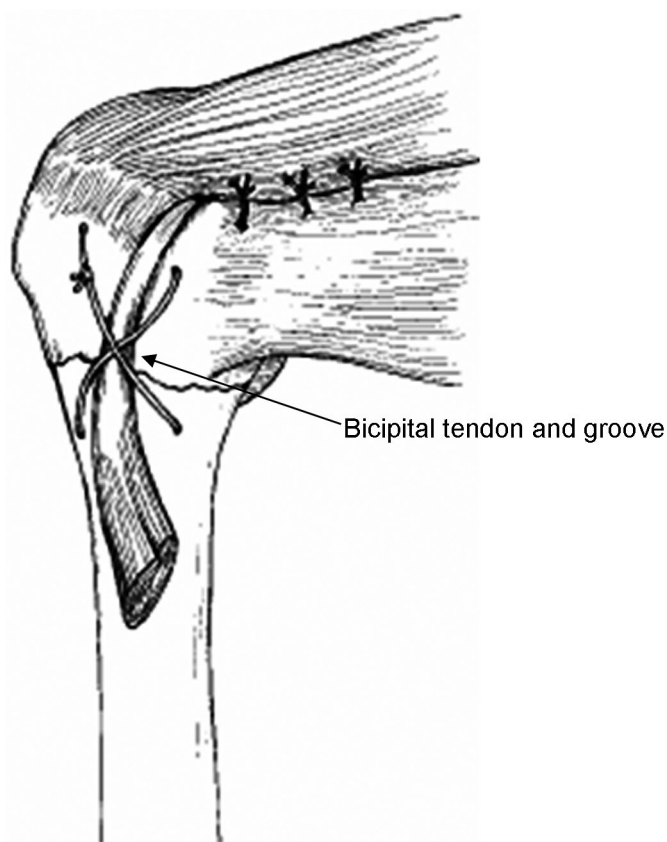


Fig. 1

Tension-band construct with transosseous suture fixation can be used for minimally displaced (AO/ASIF type-A) proximal humeral fracture involving the surgical neck, greater tuberosity, or lesser tuberosity. (Reproduced with modification, with permission from: Nho SJ, Brophy RH, Barker JU, Cornell CN, MacGillivray JD. Innovations in the management of displaced proximal humerus fractures. *J Am Acad Orthop Surg.* 2007;15:17.)

## Closed Reduction and Percutaneous Fixation

### Surgical Technique

With the aid of an image intensifier, the fracture is reduced by closed means into anatomic alignment. For surgical neck fractures, two to three threaded Kirschner wires (0.045 to 0.0625 mm) are inserted into the lateral cortex distal to the deltoid insertion and advanced into the subchondral bone of the humeral head without penetrating the articular surface. For greater tuberosity fractures in isolation or in conjunction with a surgical neck fracture, the two wires should purchase the medial cortex >20 mm from the inferior border of the head.

Resch et al.<sup>8</sup> described a technique for closed reduction and percutaneous fixation of three and four-part proximal humeral fractures. For three-part fractures, the subcapital fracture is reduced with adduction, internal rotation, and axial traction on the arm. A pointed hook retractor is inserted into the subacromial space to manipulate the greater tuberosity fragment anteriorly and inferiorly into anatomic position. Under image intensification, the shoulder is brought through internal and external rotation to confirm reduction of the greater tuberosity and two cannulated self-tapping 2.7-mm screws are used to fix the fragments.

For four-part valgus impacted fractures or true four-part fractures, a periosteal elevator is used to elevate and laterally translate the articular fragment<sup>9</sup>. When the head is elevated, the periosteum on the medial side acts as a hinge and the greater tuberosity is reduced into anatomic position. A blunt trocar and a 2.7-mm cannulated screw is advanced toward the superior aspect of the greater tuberosity, and a screw is directed toward the humeral head. Another screw is positioned at the inferior portion of the greater tuberosity and directed into the shaft to provide fixation between the head and shaft. The lesser tuberosity is provisionally fixed with a Kirschner wire, and a screw is placed from anterior to posterior.

Patients are generally immobilized for three to four weeks in most protocols. After this initial period, passive motion is started, consisting of pendulum exercises, forward elevation, and external rotation with the arm at the side<sup>10</sup>. Active motion starts at six weeks, provided that radiographs demonstrate evidence of healing.

### Indications

Percutaneous fixation of proximal humeral fractures requires less dissection and therefore less disruption of the vascular supply than traditional open approaches do. Advocates cite the high risk of osteonecrosis in these fractures as an important reason to avoid extensive exposure of the individual fragments. Percutaneous fixation also has the advantage of decreased scarring in the scapulohumeral interface and subsequent easier rehabilitation<sup>10</sup>.

### Contraindications

Contraindications include the presence of severe osteopenia or osteoporosis. Comminution of the medial portion of the calcar or proximal part of the humeral shaft is also a relative contraindication. Patients who are noncompliant or nonco-

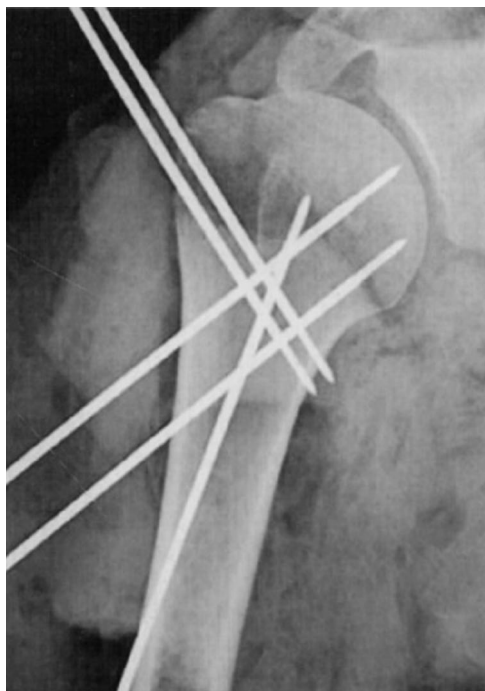


Fig. 2-A

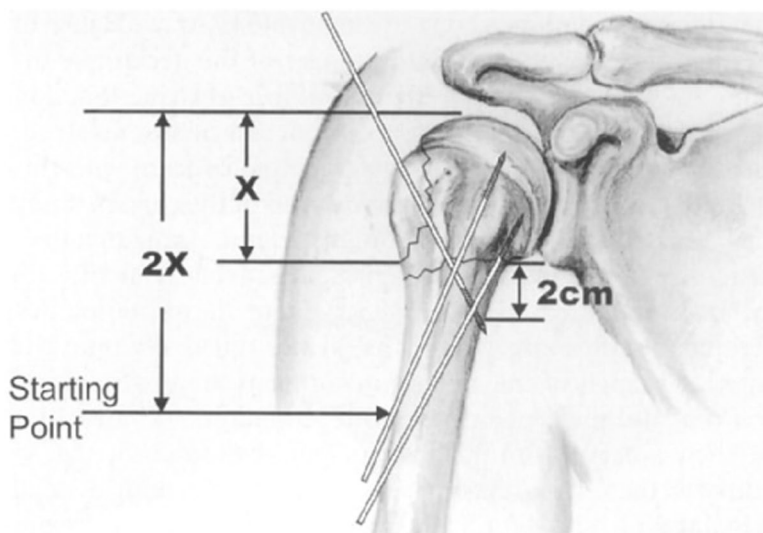


Fig. 2-B

**Fig. 2-A** Anteroposterior radiograph showing the proximal part of the humerus with percutaneous pin placement as described by Jaberg et al.<sup>13</sup>. (Reproduced from: Rowles DJ, McGrory JE. Percutaneous pinning of the proximal part of the humerus. An anatomic study. *J Bone Joint Surg Am.* 2001;83:1696.) **Fig. 2-B** The safe starting point for the proximal lateral pins and the end point for the greater tuberosity pins. X = distance from the superiormost aspect of the humeral head to the inferiormost aspect of the humeral head. 2X = the starting point for the proximal lateral pin. The end point for the greater tuberosity pin should be >2 cm from the inferiormost margin of the humeral head. (Reproduced from: Rowles DJ, McGrory JE. Percutaneous pinning of the proximal part of the humerus. An anatomic study. *J Bone Joint Surg Am.* 2001;83:1697.)

operative should not be treated with this technique. Tuberosity comminution that prevents screw or pin fixation precludes use of this technique. Finally, if a stable closed reduction cannot be obtained, an open reduction with internal fixation should be performed.

#### Pearls and Pitfalls

This procedure is technically demanding and has a substantial learning curve. Many anatomical studies have evaluated the relationship of the neurovascular structures to the pins. Rowles and McGrory<sup>11</sup> evaluated ten cadaver shoulders in which percutaneous pin fixation (two lateral, one anterior, and two greater tuberosity pins) was performed. They found that the proximal lateral pins were a mean distance of 3 mm from the anterior branch of the axillary nerve. The anterior pins were a mean distance of 2 mm from the long head of the biceps tendon and 11 mm from the cephalic vein<sup>11</sup>. The proximal tuberosity pins were a mean distance of 6 mm from the axillary nerve and 7 mm from the posterior humeral circumflex artery. The pins were found to tent these structures when the shoulder was placed in internal rotation (Figs. 2-A and 2-B)<sup>11</sup>.

Kamineni et al.<sup>12</sup> also performed a cadaver study in which the results were evaluated after inserting one anteroposterior

and two lateral Kirschner wires, as described by Jaberg et al.<sup>13</sup>, into forty shoulders. The axillary nerve was injured by the lateral wire in three specimens, and the damage included two direct penetrations. The anterior wire caused a perineural injury of a terminal branch of the axillary nerve. They concluded that fixation should be performed through a limited open approach to prevent these injuries<sup>12</sup>.

#### Results

Resch et al.<sup>8</sup> reviewed the cases of twenty-seven patients with three-part or four-part fractures treated with closed reduction and percutaneous screw fixation. For the three-part fractures, the mean Constant score was 85.4 without evidence of postoperative osteonecrosis. Thirteen of the eighteen patients with four-part fractures had valgus impacted fractures, and partial osteonecrosis developed in only one patient. Of the five laterally displaced four-part fractures, two required revision to a hemiarthroplasty.

Keener et al.<sup>10</sup>, with use of closed reduction and percutaneous fixation, treated thirty-five patients with two-part, three-part, and four-part fractures. The mean follow-up was thirty-five months. All fractures healed, and the mean pain score on a visual analog scale was 1.4. The mean American Shoulder and Elbow Surgeons score<sup>14</sup> was 83.4, and the mean

Constant score was 73.9. Osteoarthritis developed in four patients, and four fractures healed in malunion. There were no infections and no neurovascular injuries.

Fenichel et al.<sup>15</sup> retrospectively reviewed (mean follow-up, 2.5 years postoperatively) the cases of fifty patients who had unstable two or three-part fractures that were treated with percutaneous pin fixation with use of threaded pins. Excellent or good results were obtained in thirty-five pa-

tients; fair results, in eight; and poor results, in seven. The average Constant score was 81. Fractures of the surgical or anatomic neck were associated with better scores (average score, 86) than those with tuberosity fragments (average score, 78). There were no occurrences of osteonecrosis, neurovascular complications, or deep infections. Seven patients had a severe loss of reduction, however, and three of the seven needed revision surgery.



Fig. 3-A

Intraoperative photo of a patient in the beach-chair position with the c-arm over the operative shoulder.



Fig. 3-B

The c-arm is draped into the sterile field so that anteroposterior radiographs of the glenohumeral joint and radiographs of the shoulder in internal rotation and external rotation can be made.





Fig. 4-A

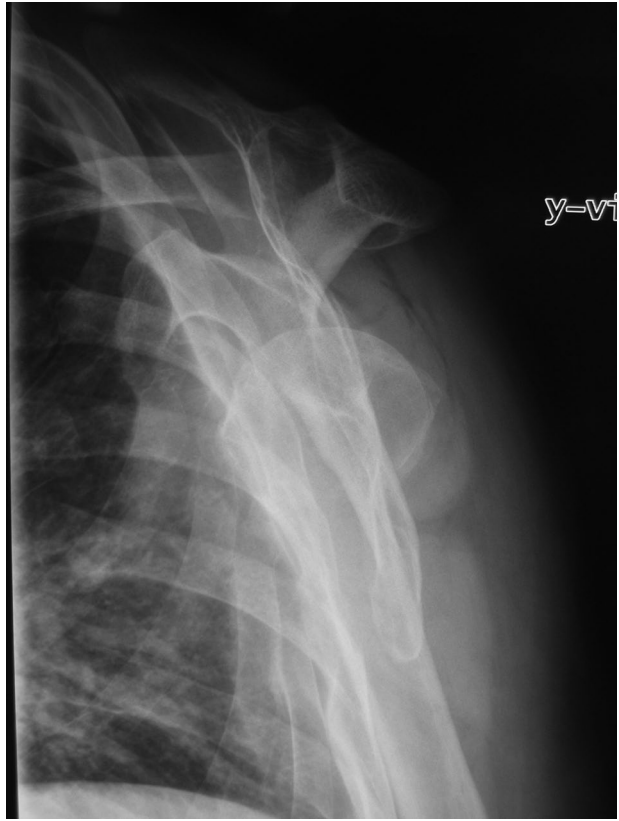


Fig. 4-B



Fig. 4-C

**Figs. 4-A, 4-B, and 4-C** Anteroposterior (Fig. 4-A), scapular Y (Fig. 4-B), and axillary (Fig. 4-C) radiographs of a proximal humeral fracture involving the surgical neck and the greater tuberosity.

### ***Open Reduction and Internal Fixation—Conventional Plate***

#### ***Surgical Technique—Double-Plate Fixation***

Wanner et al.<sup>16</sup> used two one-third tubular plates to treat patients with two, three, or four-part proximal humeral fractures. A standard deltopectoral approach was used to gain access to the fracture. An emphasis was placed on anatomical reduction, with particular attention given to reducing the greater and lesser tuberosities and achieving correct length of the humeral shaft and retroversion of the head. Lateral plate fixation to reduce the greater tuberosity was achieved first, typically with a five or six-hole one-third tubular plate. This was followed by fixation of a ventral plate at a 90° angle to the lateral plate. A four-hole one-third tubular plate with one proximal and one distal screw was usually used. Bone cement was injected into the screw holes when bone quality was deemed to be poor.

#### ***Indications***

Prior to the use of locking-plate technology, conventional plate fixation was used for the majority of patients who had open reduction and internal fixation of proximal humeral fractures. Many different plates have been used in a variety of supplementation techniques<sup>16-21</sup>. The poor bone quality in this region of the proximal part of the humerus results in a decreased ability to secure these conventional plates with screws<sup>22</sup>. The loosening and pull-out of screws are common reasons for failure<sup>23</sup>. Traditional plate techniques can still provide satisfactory outcome when anatomic reduction can be achieved<sup>18</sup>. Furthermore, double-plating techniques as described by Wanner et al. can provide satisfactory outcome<sup>16</sup>.

#### ***Contraindications***

Traditional plate constructs are usually reserved for young patients with an intact medial hinge, an adequate diaphyseal cortex (>4 mm), and no metaphyseal comminution. Patients who have osteoporosis or whose fracture lacks any of the above characteristics would likely benefit from locking-plate technology. The disadvantage of traditional plating systems is the high rate of osteonecrosis due to extensive soft-tissue dissection. The rate of osteonecrosis has been reported to be as high as 35% in some case series<sup>18,21</sup>.

#### ***Results***

Wanner et al.<sup>16</sup> treated sixty shoulders with one-third tubular plates fixed orthogonally on the anterior and lateral cortices. Sixty-three percent of the patients had good or very good results. Seven patients (12%) had complications that included fracture displacement, osteonecrosis, adhesive capsulitis, subacromial impingement, and hardware loosening. Conventional plate fixation may produce satisfactory clinical results even in the setting of osteonecrosis<sup>18,21</sup>; however, anatomic reduction with conventional plate fixation in the absence of osteonecrosis produces superior clinical results<sup>18</sup>.

### ***Open Reduction and Internal Fixation—Locked Plate***

#### ***Surgical Technique***

We prefer to place the patient in the beach-chair position with the c-arm placed over the shoulder and draped into the sterile field. The c-arm fluoroscopic image intensifier provides an anteroposterior view of the glenohumeral joint, and the humerus can be rotated to obtain radiographs of the

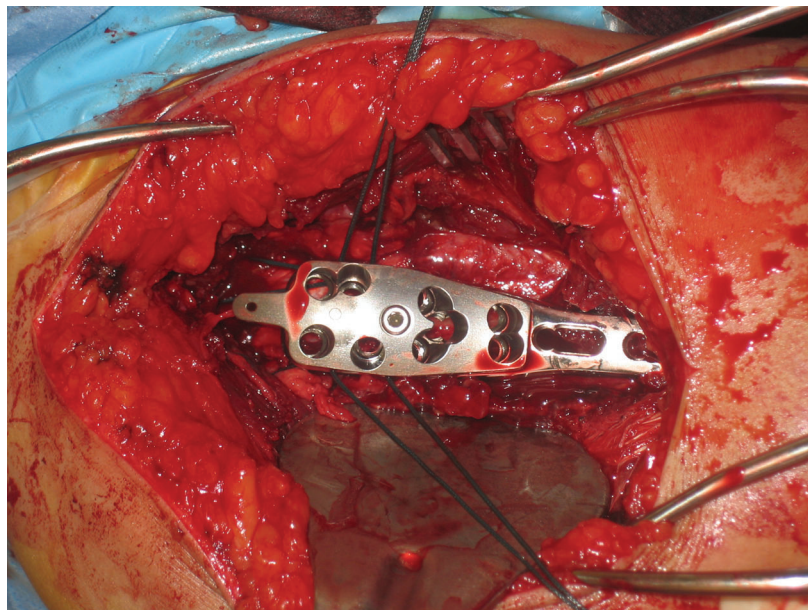


Fig. 4-D

Tagging sutures are used to obtain reduction of the tuberosity fracture and then are passed through the suture holes in the proximal humeral locking plate.

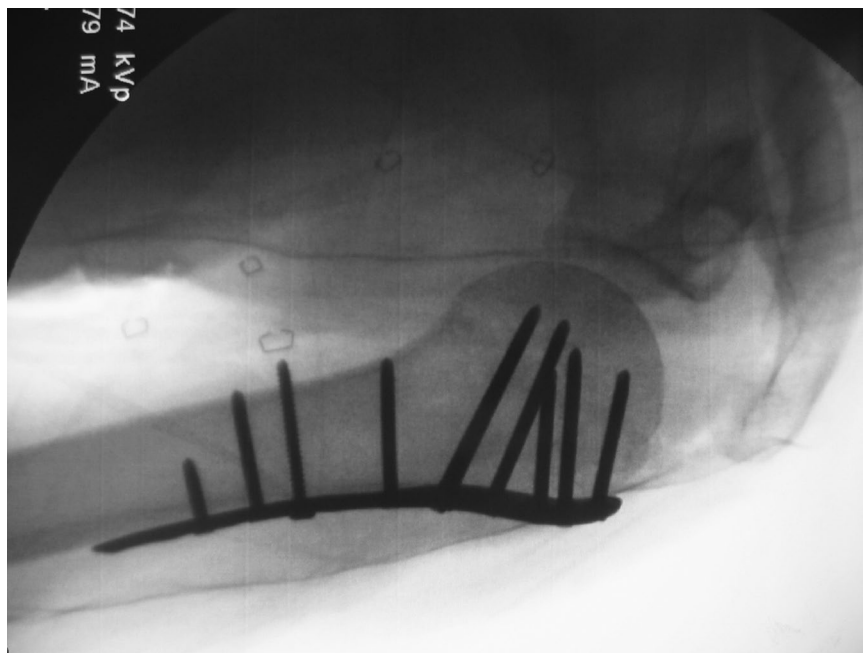


Fig. 4-E



Fig. 4-F

**Figs. 4-E and 4-F** Anteroposterior (Fig. 4-E) and lateral (Fig. 4-F) fluoroscopic images demonstrating anatomic reduction with restoration of the medial portion of the calcar.

shoulder in internal and external rotation (Figs. 3-A and 3-B). We use a standard deltopectoral approach to the shoulder. The anterior third of the deltoid may be reflected to allow greater exposure of the proximal part of the humerus. The rotator cuff tendons are tagged with multiple number-2 braided nonabsorbable sutures, whether as a part of a tuber-

osity fragment or in continuity with the head fragment. The tagging sutures are used to bring the tuberosity fragments in continuity with the lateral cortex of the shaft fragment, which may indirectly reduce the head fragment to the shaft. If the head fragment is impacted onto the shaft, a periosteal elevator can be inserted into the fracture site to disimpact



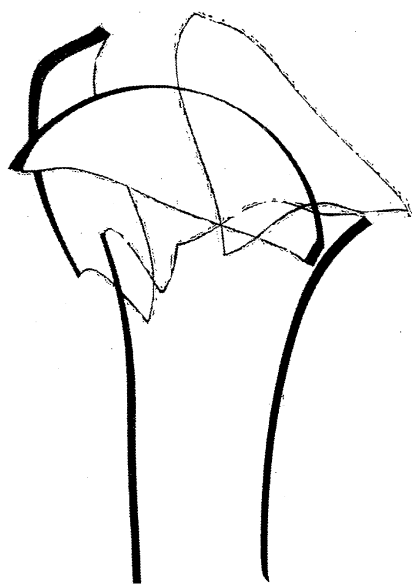


Fig. 5-A

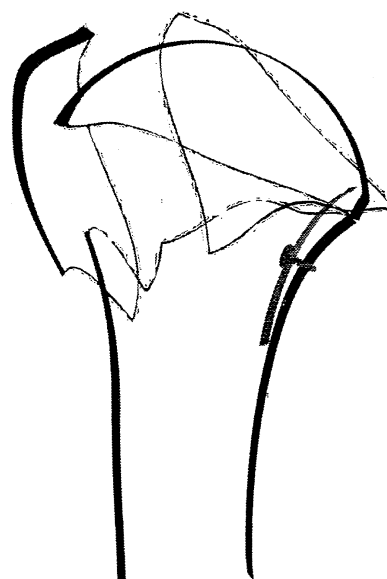


Fig. 5-B

**Figs. 5-A and 5-B** Drawing showing a proximal humeral fracture with a disrupted medial hinge (Fig. 5-A) that has been reconstituted with a 2.0-mm intramedullary plate as a preliminary reduction (Fig. 5-B). (Reproduced, with permission, from: Sperling JW, Cuomo F, Hill JD, Hertel R, Chuinard C, Boileau P. The difficult proximal humerus fracture: tips and techniques to avoid complications and improve results. Instr Course Lect. 2007;56:52.)

the head and thus restore the medial portion of the calcar. When the fracture is anatomically reduced, the tagging sutures are passed through the suture holes of the proximal humeral locking plate. The plate should be positioned directly on the middle of the lateral cortex and approximately 8 mm distal to the superior aspect of the greater tuberosity. Some plates have an oblong hole at the level of the humeral shaft into which a cortical screw can be partially advanced to allow the height of the plate to be adjusted; once the plate is in the correct position, the cortical screw can be completely advanced to secure the plate. With use of the insertion guide and sleeve assembly, the locked screws can be placed in the humeral head. After achieving fixation in the humeral head, at least three diaphyseal screws are inserted. The final fluoroscopic images should demonstrate anatomic reduction of the proximal humeral fracture (Figs. 4-A through 4-F).

#### Indications

For AO/ASIF type-B (bifocal) and type-C (anatomic neck) proximal humeral fractures<sup>24</sup>, humeral head preservation may be possible with locked-plate fixation supplemented with local bone graft or bone-graft substitute. Because of the fixed-angle relationship between the plate and screws, locked-plate fixation provides a mechanical advantage in fractures with metaphyseal comminution, particularly when there is insufficient osseous contact opposite the plate<sup>25</sup>. The indications for locked-plate fixation continue to evolve as long-term outcomes after locked-plate fixation for proximal humeral fractures become available.

#### Contraindications

Open reduction and internal fixation with locked-plate fixation is contraindicated in some fracture-dislocations, head-splitting fractures, and impression fractures that involve >40% of the articular surface<sup>26-28</sup>.

#### Pearls and Pitfalls

As in other applications of locked-plate fixation, the proximal humeral fracture must be reduced prior to placement of the hardware. The precontoured proximal humeral locking plate must be placed at the appropriate height, as an excessively superior position may cause impingement of the plate on the acromion. Restoration of the medial hinge is critical to successful anatomic healing of the proximal humeral fracture. If the medial hinge is disrupted, it must be reduced. Some advocate the use of a 2.0-mm intramedullary plate to maintain the reduction (Figs. 5-A and 5-B)<sup>29</sup>. In cases of comminution or malreduction of the medial hinge, the placement of calcar-specific screws is critical to support the medial column and therefore maintain fracture reduction<sup>30</sup>. If calcar screws are necessary, the plate must be positioned to ensure that the screw will purchase the inferior part of the calcar<sup>30</sup>.

#### Results

From 2002 to 2004, the senior authors (C.N.C. and J.D.MacG.) managed patients with AO/ASIF type-B proximal humeral fractures with open reduction and locked-plate fixation. Eight patients (six women and two men) with an average age of sixty-nine years and a mean follow-up of fifteen months were

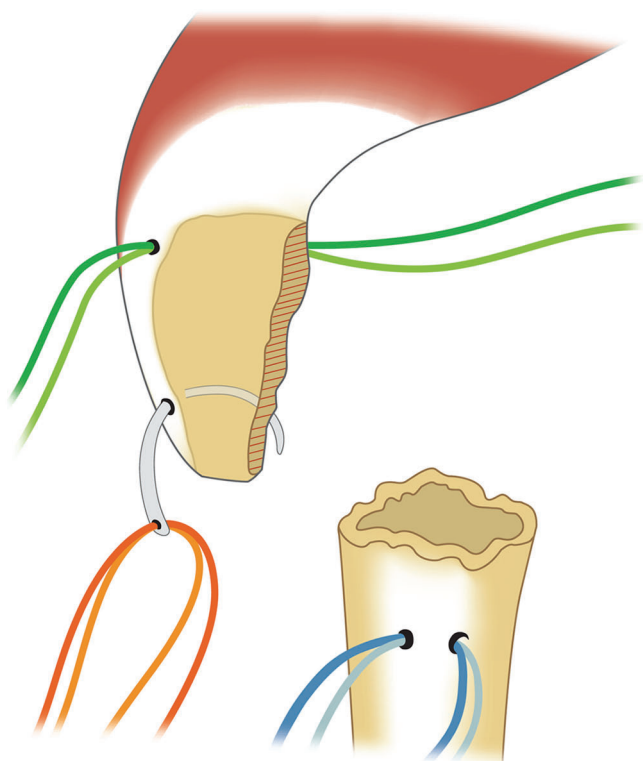


Fig. 6-A

evaluated with subjective questionnaires, physical examination, and plain radiographs. The injured shoulders demonstrated a mean forward flexion of 110° and a mean abduction of 99°. The contralateral shoulders exhibited a mean forward flexion of 168° and a mean abduction of 159°. Shoulder strength was slightly lower in the injured shoulders (mean, 13.2 lb [5.9 kg]) than in the contralateral shoulders (mean, 15.9 lb [7.2 kg]). The mean Constant score for the injured shoulders was 70.4 compared with 88.8 for the contralateral shoulders. The mean Neer score was 76.3 for the injured and 95.4 for the contralateral shoulders. All radiographs demonstrated evidence of excellent healing and well-positioned implants. There was no evidence of hardware loosening, failure, or nonunion.

### *Hemiarthroplasty*

#### **Surgical Technique**

The technique for shoulder hemiarthroplasty is well described in the literature and follows the principles originally outlined by Neer<sup>31-35</sup>. Typically, a standard deltopectoral ap-

**Figs. 6-A through 6-D** Anatomical suture technique<sup>38</sup>. **Fig. 6-A** Sutures are placed in the greater tuberosity fragment and the humeral shaft.

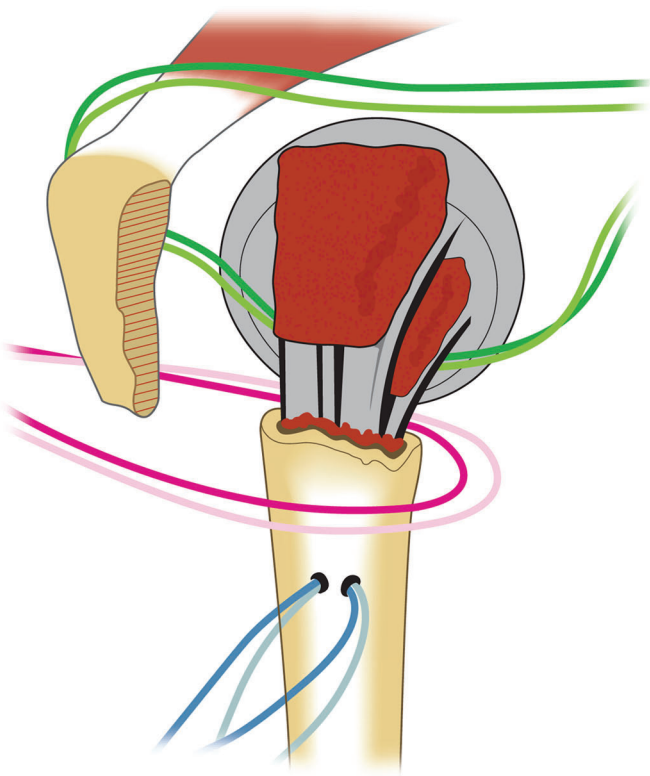


Fig. 6-B

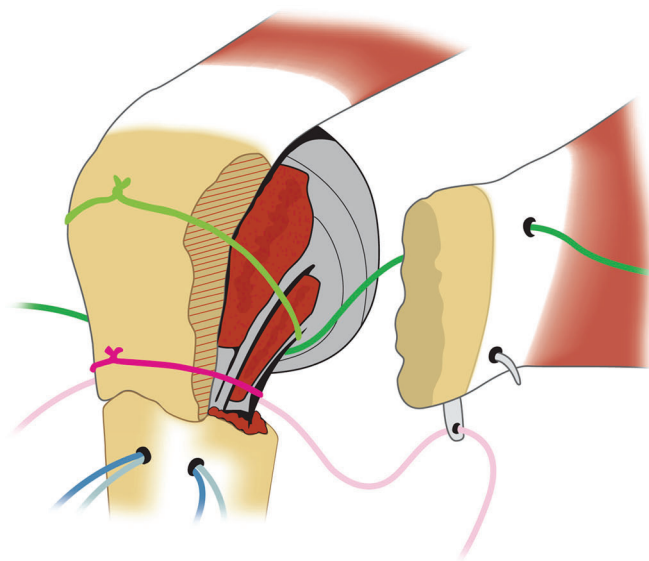


Fig. 6-C

**Figs. 6-B and 6-C** Sutures are passed medial to the humeral neck and subsequently tied around the greater tuberosity fragment while the involved arm is held in neutral position. The lesser tuberosity fragment is fixed with the remaining two sutures.

proach is used. Deep soft-tissue dissection may be minimal, depending on the fracture pattern and soft-tissue injury. It is essential to identify and tag the tuberosities with use of sutures at the bone-tendon junction to gain control of the rotator cuff and its insertion. The humeral head and shaft fragments are then exposed, and sutures are passed through drill holes in the shaft. The glenoid should be carefully inspected to determine if a glenoid component is warranted.

Once the joint has been adequately exposed and cleaned, preparation of the humeral shaft begins. It is critical to place the humeral component so that it has the correct amount of height and retroversion (typically 30° to 40°); to accomplish this, the bicipital groove can be used as a landmark<sup>36</sup>. Different trial modular heads can be used to identify the optimal configuration. For most joints, the stem should be cemented to ensure rotational control of the prosthesis. Once the humeral component is secure, bone graft may be placed to promote healing between the tuberosities and the shaft.

Finally, the proximal anatomy is restored, with particular emphasis on correct and secure positioning of the tuberosities through a variety of suturing techniques. Our preferred technique (Figs. 6-A through 6-D) is to pass the greater tuberosity cerclage sutures medial to the humeral neck and tie them around the greater tuberosity fragment. In biomechanical studies, the incorporation of medial circumferential cerclage around the tuberosities decreased interfragmentary motion and strain, maximized fracture stability, and facilitated post-

operative rehabilitation<sup>37,38</sup>. A second set of sutures can then be passed into the lesser tuberosity and tied. Ideally, a vertical tension band can be used to fix the tuberosities to the shaft. The shoulder should be taken through a range of motion before the wound is closed to ensure that stable fixation has been achieved.

#### Indications

Hemiarthroplasty is indicated as the treatment for proximal humeral fractures (four-part fractures, three-part fractures in older patients with osteoporotic bone, fracture-dislocations, head-splitting fractures, and impression fractures) that involve >40% of the articular surface<sup>26,27,39</sup>. The tenuous fixation of fracture fragments in osteoporotic bone<sup>39</sup> and the high rate of osteonecrosis that is seen in the humeral head after healing of three or four-part fractures suggest that hemiarthroplasty provides a better treatment alternative for these fracture patterns.

#### Contraindications

Active infection of the shoulder joint and/or the surrounding soft tissue is an absolute contraindication to hemiarthroplasty. Open reduction and internal fixation should be considered in younger patients, particularly those with good bone stock, even when the fracture pattern is complicated. Patients need to undergo intensive rehabilitation to achieve an optimal outcome after hemiarthroplasty, and individuals who cannot do so for medical or psychological reasons are not good candidates for hemiarthroplasty.

#### Pearls and Pitfalls

Hemiarthroplasty for the treatment of proximal humeral fracture is a demanding operation, and many variables, including patient factors, surgical technique, and rehabilitation, can influence outcome after this procedure. To maximize the probability of an optimal outcome, surgeons should pay particular attention to two important goals: restoring the tuberosities to an anatomical position, and placing the humeral component in the correct amount of version.

The importance of anatomical restoration of the tuberosities, including secure fixation and restoration of humeral length and retroversion, cannot be overemphasized (Figs. 7-A and 7-B). Malunion or nonunion of tuberosity osteosynthesis is the most common and perhaps most serious complication that can occur after hemiarthroplasty for displaced proximal humeral fractures. Ideally, the humeral implant should have a low-profile lateral fin to facilitate proper positioning and suture fixation of the tuberosity. The mean head-to-tuberosity distance (and standard deviation) should be  $8 \pm 3$  mm as shown by Frankle et al.<sup>37</sup> and Mighell et al.<sup>26</sup>. Factors that have been shown to be associated with tuberosity malunion include poor intraoperative positioning of the prosthesis (excessive height and/or retroversion), the initial tuberosity position, patient age in excess of seventy-five years, and female gender<sup>40</sup>.

Loss of anatomic landmarks makes restoration of humeral height difficult. Shortening the humerus decreases the

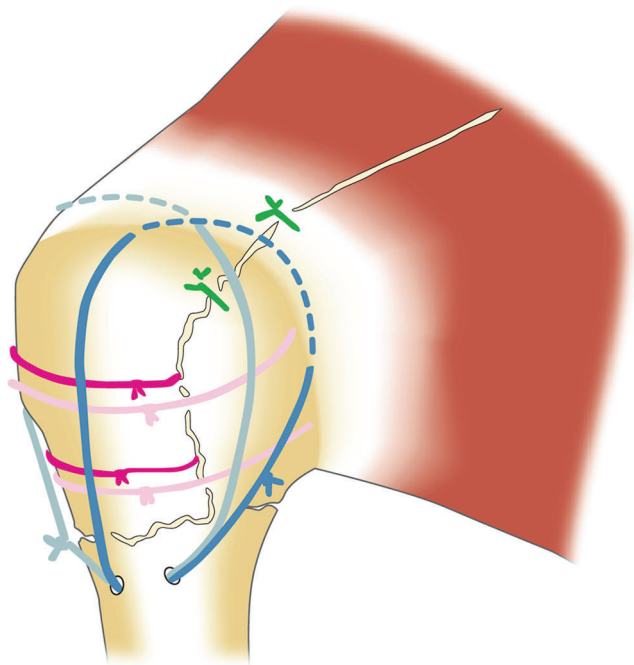


Fig. 6-D

The final construct, with the tuberosity sutures and the tension-band suture from the shaft placed through the rotator cuff tendons to complete the repair.

lever arm of the deltoid muscle and therefore decreases the motion and power of that muscle in forward elevation. Lengthening may contribute to superior humeral migration and impingement and/or nonunion of the tuberosity.

Most authors recommend 30° to 40° of retroversion, typically with use of the bicipital groove as the landmark for orientation of the prosthesis<sup>36</sup>, although an individualized approach has been proposed in which the contralateral humerus is used for comparison to estimate the proper amount of retroversion for each patient<sup>41</sup>. The tendency is to position the humeral head in excessive retroversion because of imprecise landmarks and the desire to prevent anterior dislocation. Placement of the head in too much retroversion may lead to excessive posterior rotator cuff tension, suture pull-out, and malunion or nonunion of the greater tuberosity.

Another point to remember is that restoration of the epiphyseal width is critical to reproducing the soft-tissue tension of the deltoid and supraspinatus muscles. The opposite shoulder can be used as a template to gauge the epiphyseal width.

The optimal timing of hemiarthroplasty is important. Most recent reports<sup>26,42</sup> have shown that acute treatment is generally preferable to later hemiarthroplasty because acute hemiarthroplasty is technically easier to perform; however, one study found no difference between early or late treatment when a breakpoint of thirty days after injury was used<sup>43</sup>.

## Results

While hemiarthroplasty has been shown to provide good pain relief, the achievement of excellent range of motion with this method has been less predictable. Rehabilitation, particularly passive range of motion in the early stage<sup>41,44</sup> and long-term active range of motion and strengthening, is considered essential to the achievement of an optimal outcome after shoulder hemiarthroplasty<sup>41,43</sup>. The results obtained in recent studies of hemiarthroplasty for proximal humeral fractures have been reasonably good, although not quite as good as the results reported in earlier studies<sup>26,39-45</sup>.

In a retrospective multicenter review, Kralinger et al.<sup>44</sup> found that patients with healed, undisplaced tuberosity fractures had significantly higher Constant scores and subjective patient satisfaction ( $p = 0.0001$ ) than patients whose tuberosities did not heal or healed with >0.5 cm of displacement. Pain did not correlate with displacement of the tuberosity, however.

Robinson et al.<sup>45</sup> retrospectively reviewed the results of shoulder hemiarthroplasty for proximal humeral fractures at a single center and found consistent improvement in the Constant score from six weeks to six months postoperatively but little change thereafter. At one year, patients reported reasonable pain relief but poorer scores for function, range of motion, and strength. Factors assessed six weeks postoperatively that predicted the one-year Constant score included patient

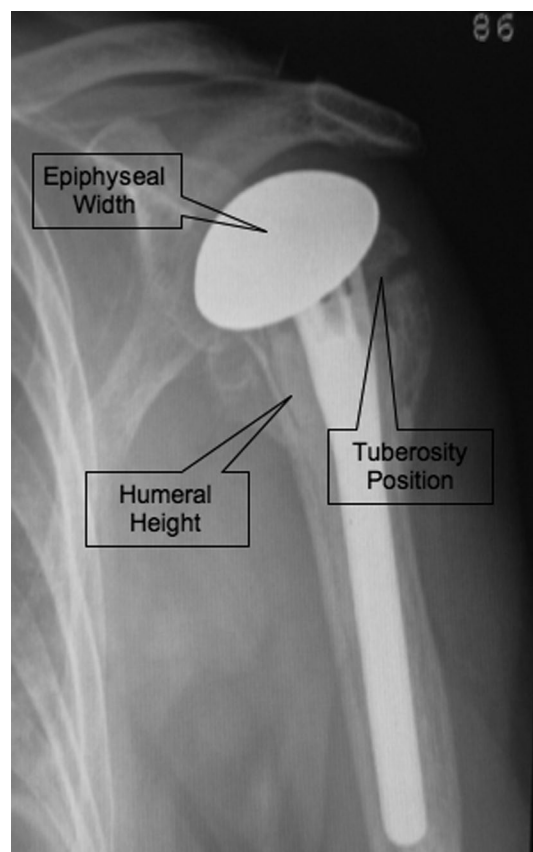


Fig. 7-A

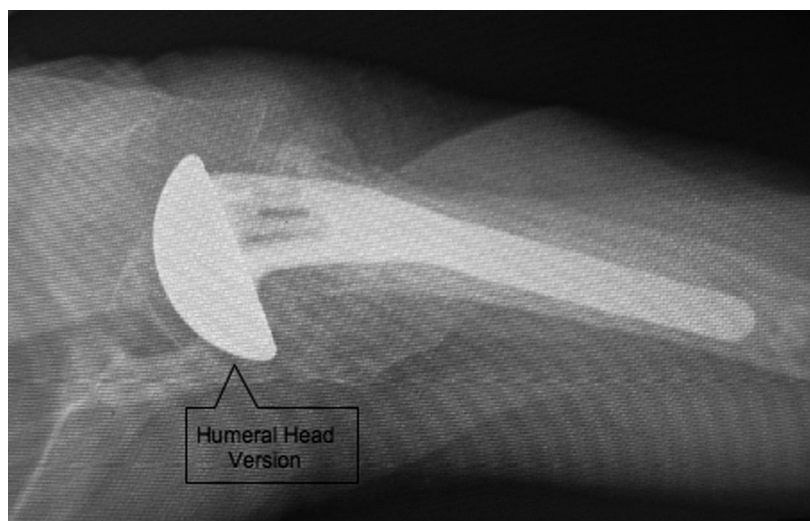


Fig. 7-B

**Fig. 7-A** Anteroposterior radiograph of the shoulder, demonstrating appropriate humeral length, tuberosity position, and epiphyseal width. **Fig. 7-B** Axillary radiograph of the shoulder, demonstrating the appropriate amount of humeral head retroversion.

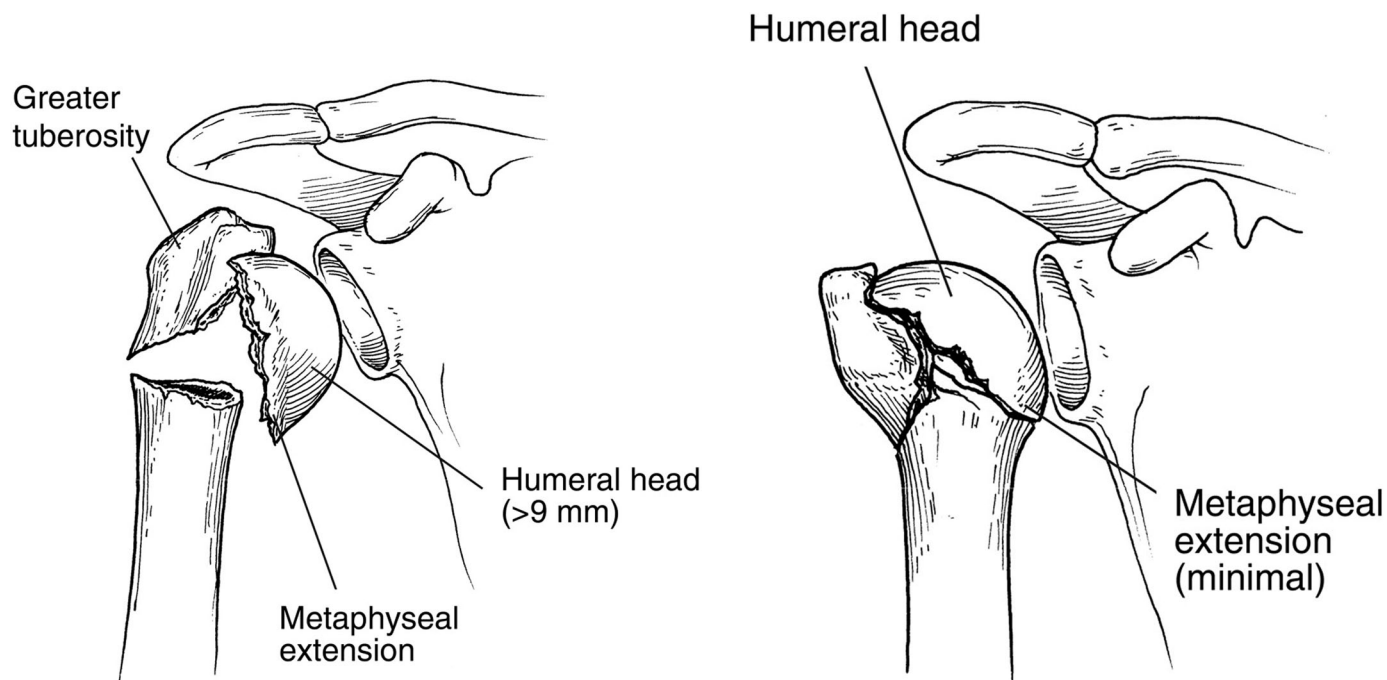


Fig. 8-A

Fig. 8-B

**Figs. 8-A through 8-D** Hertel radiographic criteria. **Fig. 8-A** Metaphyseal extension of the humeral head of >9 mm. **Fig. 8-B** Metaphyseal extension of the humeral head of <8 mm.

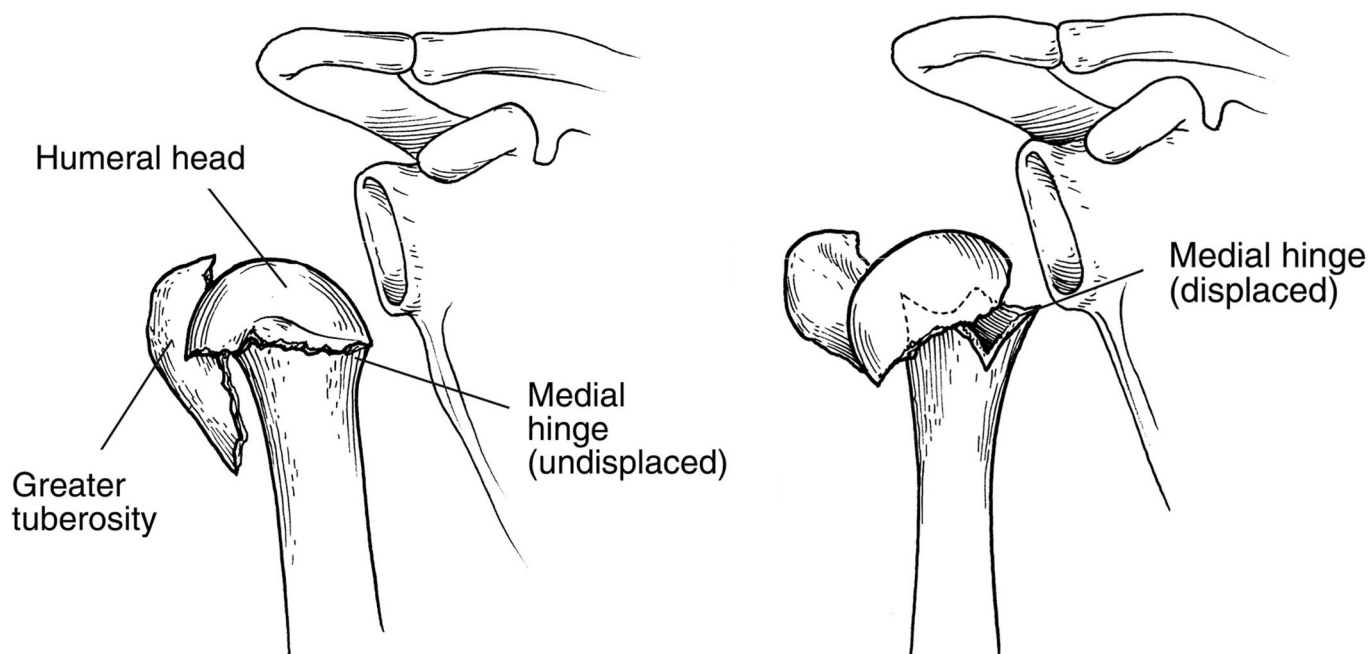


Fig. 8-C

Fig. 8-D

**Fig. 8-C** Undisplaced medial hinge. **Fig. 8-D** Medial hinge with >2 mm of displacement. (Reprinted, with modification, with permission from: Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Elbow Surg. 2004;13:427-33.)



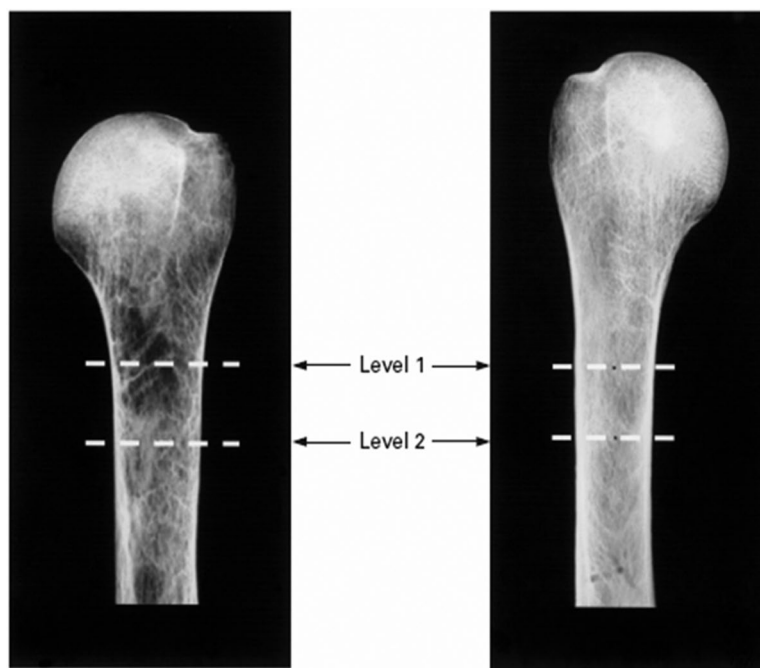


Fig. 9

Combined cortical thickness is measured at two levels of the humeral diaphysis. Level 1 occurs at the level in which the endosteal borders of the medial and lateral cortices are parallel. Level 2 is 20 mm distal to Level 1. *Left image*, Humerus of a patient with low bone-mineral density. *Right image*, Humerus of a patient with high bone-mineral density. (Reproduced, with permission, from: Tingart MJ, Apreleva M, von Stechow D, Zurakowski D, Warner JJ. The cortical thickness of the proximal humeral diaphysis predicts bone mineral density of the proximal humerus. *J Bone Joint Surg Br.* 2003;85:612.)

age, a persistent neurological deficit, the need for early reoperation, and the degree of displacement of both the prosthetic head (<5 mm displacement of the prosthetic head from the central axis of the glenoid) and the tuberosities.

### Discussion

The treatment of displaced proximal humeral fractures is complex and requires careful assessment of patient factors (such as age and activity level) and fracture-related factors (such as bone quality, fracture pattern, degree of comminution, and vascular status). The goal of treatment is a pain-free shoulder with restoration of pre-injury function.

The first step is to assess the vascular status of the humeral head with use of the Hertel radiographic criteria for perfusion of the humeral head<sup>46</sup> and the AO/ASIF classification of fractures of the proximal part of the humerus<sup>24</sup>. In the Hertel criteria, metaphyseal extension of the humeral head of <8 mm and medial hinge disruption of >2 mm were determined to be good predictors of ischemia (Figs. 8-A through 8-D)<sup>46</sup>. The combination of metaphyseal extension of the humeral head, medial hinge disruption of >2 mm, and an anatomic neck fracture pattern had a 97% positive predictive value for humeral head ischemia<sup>46</sup>. The AO/ASIF classification for proximal humeral fractures provides information

about the energy and severity of the fracture and the likelihood of vascular injury. Type A is a unifocal, extra-articular fracture with an intact vascular supply. Type B is a bifocal, extra-articular fracture with possible injury to the vascular supply. Type C is an articular fracture of the anatomic neck with a high probability of osteonecrosis<sup>24</sup>.

Once a proximal humeral fracture has been determined to have adequate blood supply, the operative management is guided by the fracture pattern and the cortical thickness. The AO/ASIF classification provides a guide in the degree of surgical intervention required for successful treatment. The cortical thickness of the humeral diaphysis is a more reliable and reproducible predictor of bone mineral density and the potential of success of internal fixation than is patient age<sup>47</sup>. The combined cortical thickness is the average of the medial and lateral cortical thickness at two levels (Fig. 9). A cortical thickness of <4 mm is appropriate for sling immobilization, osteosuture, and hemiarthroplasty. Adequate screw purchase with standard internal fixation requires a cortical thickness of >4 mm.

AO/ASIF type-A fractures are generally treated with sling immobilization (Fig. 10). Proximal humeral fractures with surgical neck translation of >66% or tuberosity displacement of >5 mm may benefit from transosseous suture fixation (cortex <4 mm) or closed reduction and percutane-

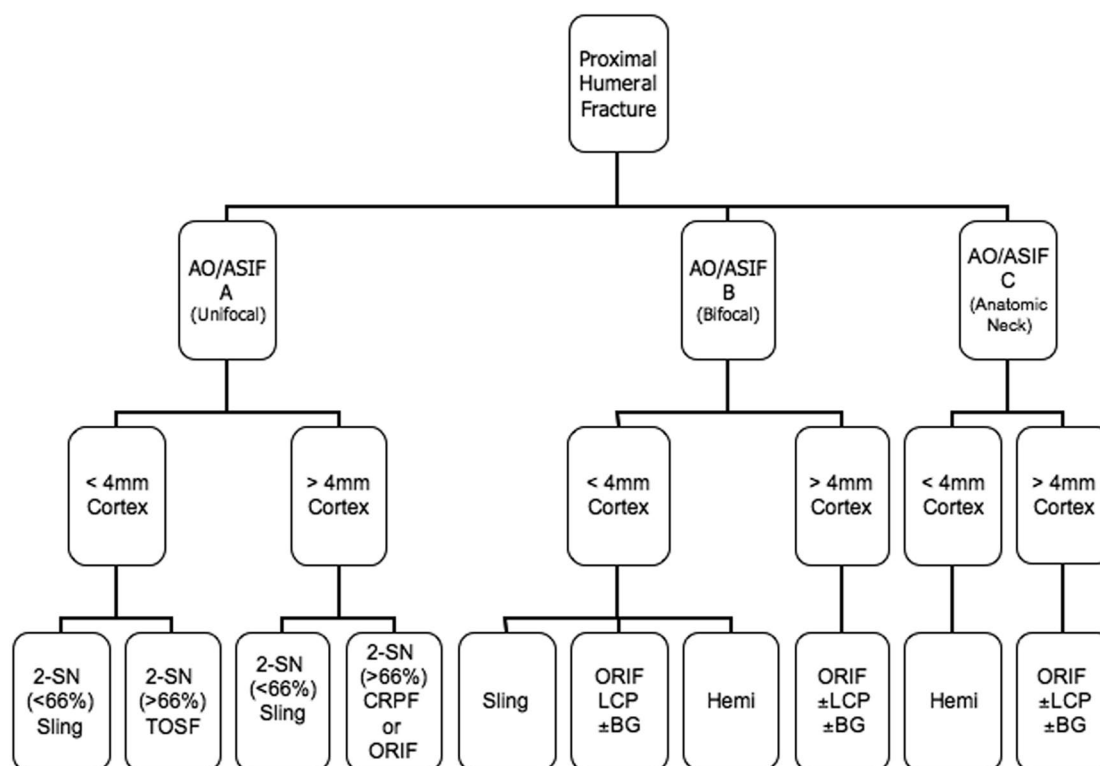


Fig. 10

Treatment algorithm for displaced proximal humeral fractures. 2-SN (<66%) = two-part surgical neck fracture with <66% translation. 2-SN (>66%) = two-part surgical neck fracture with >66% translation. BG = bone graft or bone-graft substitute. CRPF = closed reduction and percutaneous fixation. Hemi = hemiarthroplasty. LCP = locked compression plate. ORIF = open reduction and internal fixation. TOSF = transosseous suture fixation. (Reproduced in modified form, with permission, from: Nho SJ, Brophy RH, Barker JU, Cornell CN, MacGillivray JD. Innovations in the management of displaced proximal humerus fractures. *J Am Acad Orthop Surg*. 2007;15:15.)

ous fixation (cortex >4 mm). For multifragment fractures, open reduction with locked-plate fixation allows preservation of the periosteal blood supply and is appropriate for cortices less than or greater than 4 mm, regardless of the thickness of the cortex. Recent studies have emphasized the importance of stabilizing the medial column to prevent varus malunion, plate failure, screw cutout, and impingement. In cases with an adequate medial cortex, the medial hinge should be reduced; in cases with medial comminution, calcar-specific screws should be used to stabilize the medial column. Local adjuvants, such as calcium phosphate cement, demineralized bone matrix, or allografts, may improve the rate of union and minimize malunion. Hemiarthroplasty is

the treatment of choice for fractures with vascular compromise, certain fracture-dislocations, head-splitting fractures, and impression fractures with >40% of articular surface involvement, although locking-plate technology is allowing surgeons to attempt fixation in some of these fractures, particularly in younger patients. ■

Corresponding author:

Shane J. Nho, MD, MS

The Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021. E-mail address: nhos@hss.edu

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