# Innovations in the Management of Displaced Proximal Humerus Fractures

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## Abstract

The management of displaced proximal humerus fractures has evolved toward humeral head preservation, with treatment decisions based on careful assessment of vascular status, bone quality, fracture pattern, degree of displacement, and patient age and activity level. The AO/ASIF fracture classification is helpful in guiding treatment and in stratifying the risk for associated disruption of the humeral head blood supply. Nonsurgical treatment consists of sling immobilization. For patients requiring surgery, options include closed reduction and percutaneous fixation; transosseous suture fixation; open reduction and internal fixation, with either conventional or locking plate fixation; bone graft; and hemiarthroplasty. Proximal humerus fractures must be evaluated on an individual basis, with treatment tailored according to patient and fracture characteristics.

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Proximal humerus fractures are increasingly common in societies with maturing populations.[1] These fractures are not simple to treat. A variety of options exists; however, outcomes are less than ideal in many patients.[2,3] Most proximal humerus fractures are either nondisplaced or minimally displaced and can be treated nonsurgically.[4] Nonsurgical options focus on early functional exercises with the goal of achieving a functionally acceptable range of motion (ROM). For the 15% to 20% of displaced proximal humerus fractures that may benefit from surgery, no single approach is considered to be the standard of care. Surgeons should be familiar with the different treatment options available, including recent advances in the management of complex periarticular fractures[5-11] and in locking plate technology,[8,12] which are particularly relevant to the care of these fractures.[7,13-15] Locking plate technology and the use of osteobiologics may become increasingly important in the management of displaced proximal humerus fractures, facilitating humeral head preservation in appropriately selected patients.

## Epidemiology

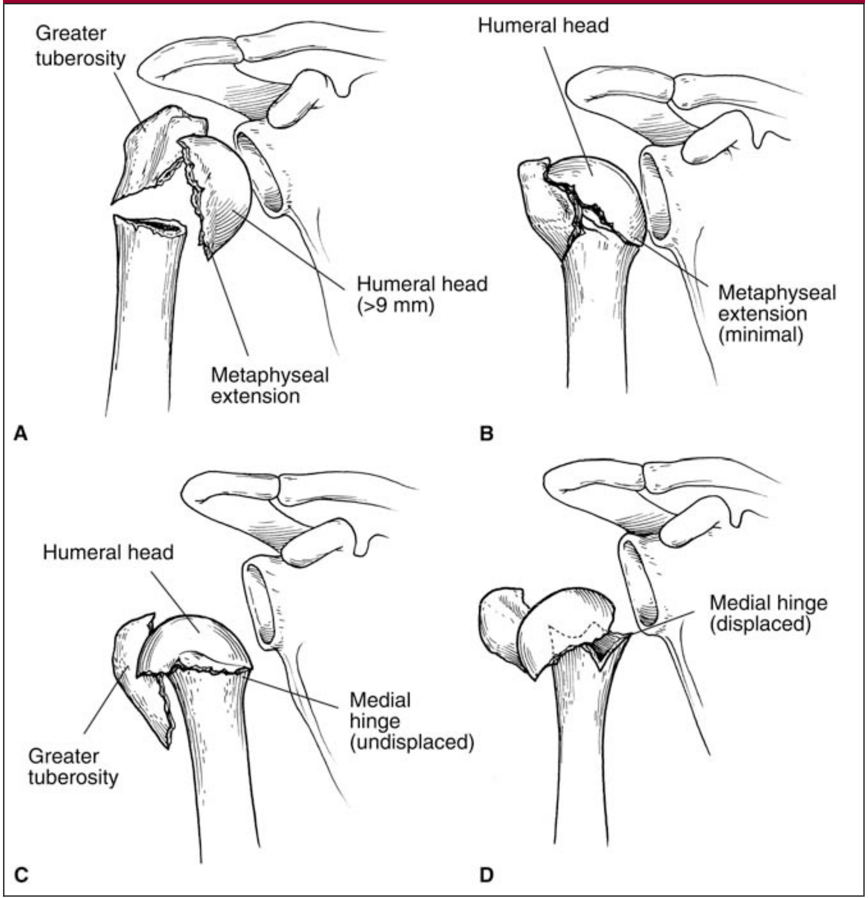
Proximal humerus fracture is the second most common fracture of the upper extremity, following distal forearm fracture.[1] In people older than age 65 years, fracture of the proximal humerus is the third most common fracture, after hip fracture and Colles' fracture.[1] Proximal humerus fracture is associated with significant morbidity, leading to functional impairment lasting at least 3 months.[16] Displaced proximal humerus fractures generally result in long-term functional disability. This type of injury usually is sustained after a moderate-energy fall in an individual with low bone density.[16]

## Anatomy

The proximal humerus is divided into the shaft, surgical neck, anatomic neck, lesser tuberosity, and greater tuberosity. Classification of proximal humerus fractures based on these anatomic divisions predicates treatment and predicts outcome. The humeral head has a spherically shaped articular surface; the anatomic neck demarcates the junction of the head and metaphysis. The neck-shaft angle is 130°, and the head is retroverted 19° to 22° relative to the shaft.[17] The greater and lesser tuberosities are located adjacent to the articular margin of the head; they are separated by the bicipital groove. The surgical neck serves as the junction between the metaphysis and the humeral diaphysis.

Tendinous insertions contribute to the pattern of fracture displacement around the proximal humerus by transmitting deforming muscular forces to the bony fragments. The insertions of the supraspinatus, infraspinatus, and teres minor tendons onto the greater tuberosity contribute to the typical posterior and superior retraction of this fragment. The rotator interval functions as a checkrein on the humeral head fragment and limits displacement of two-part fractures and most three-part fractures. Functionally significant tears of the rotator interval are uncommon. The pull of the subscapularis muscle tends to retract lesser tuberosity fragments medially. When the lesser tuberosity remains attached to the head fragment, the head fragment is rotated internally. Although the bone at the tendinous insertion tends to be very dense and strong, thus providing a potential site for fracture fixation, it is important when using suture fixation to remember that the tendons are even stronger than the bone.[18]

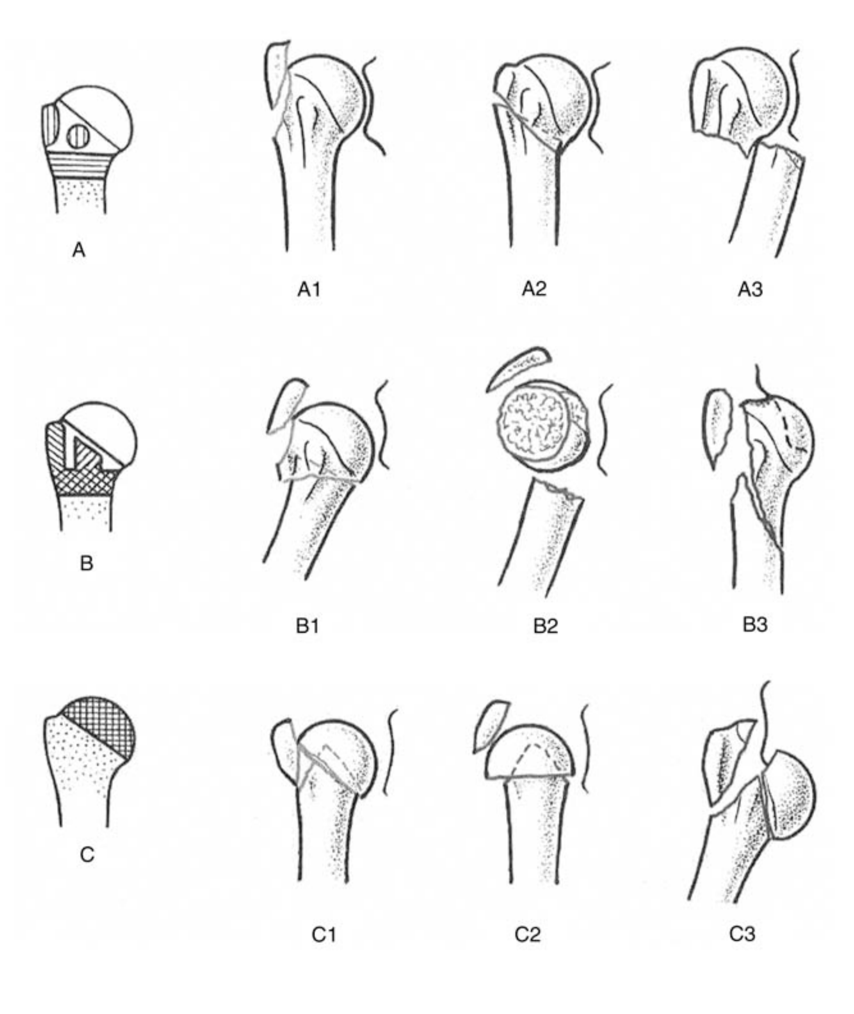
**Figure 1**




Hertel radiographic criteria. **A** and **B,** Metaphyseal head extension is a radiographic measurement of the articular fragment from the head-neck junction to the inferior extent of the medial cortex. **A,** Metaphyseal head extension >8 mm. **B,** Metaphyseal head extension <8 mm. **C** and **D,** Medial hinge integrity is determined by the continuity of the medial calcar. **C,** Undisplaced medial hinge. **D,** Medial hinge displaced >2 mm. (Adapted with permission from Hertel R, Hempfing A, Stiehler M, Leunig M: Predictors of the humeral head ischemia after intracapsular fracture of the proximal humerus. *J Shoulder Elbow Surg* 2004;13:427-433.)

The anterior circumflex humeral artery and the arcuate artery are considered to be the major sources of humeral head perfusion,[19] but studies characterizing the vascular anatomy were performed in the intact proximal humerus.[20,21] Even in simple fracture patterns, the anterior circumflex humeral artery is often disrupted, implying, in the fractured proximal humerus that perfusion from the posterior circumflex humeral artery alone may be sufficient for humeral head survival. Hertel et al[22] conducted perfusion studies in proximal humerus fractures to determine factors predictive of humeral head ischemia. They demonstrated the significance of metaphyseal head extension (ie, the amount of metaphysis, typically posteromedial) that remains attached to the humeral head determines the amount of head extension[22] (Figure 1, A). Meta-

Figure 2




AO/ASIF classification for proximal humerus fractures. *Top*, A, Unifocal, extra-articular two-part fracture with intact vascular supply. *Middle*, B, Bifocal extra-articular fracture with possible injury to the vascular supply. *Bottom*, C, Articular fracture involving the anatomic neck, with high likelihood of necrosis. (Adapted with permission from Müller ME: Appendix A: The comprehensive classification of fractures of long bones, in Müller ME, Allgöwer M, Schneider R, Willenegger H [eds]: *Manual of Internal Fixation: Techniques Recommended by the AO-ASIF Group*. Berlin, Germany: Springer-Verlag, 1991, pp 118-125.)

physeal head extension <8 mm was found to be a good predictor of ischemia (accuracy, 0.84).[22] Another predictor of ischemia was medial hinge disruption >2 mm (accuracy, 0.79)[22] (Figure 1, B). In this series, the combination of metaphyseal head extension <8 mm with medial hinge disruption >2 mm as well as an anatomic neck fracture pattern had a positive predictive value of 97% for humeral head ischemia.[22]

## Classification

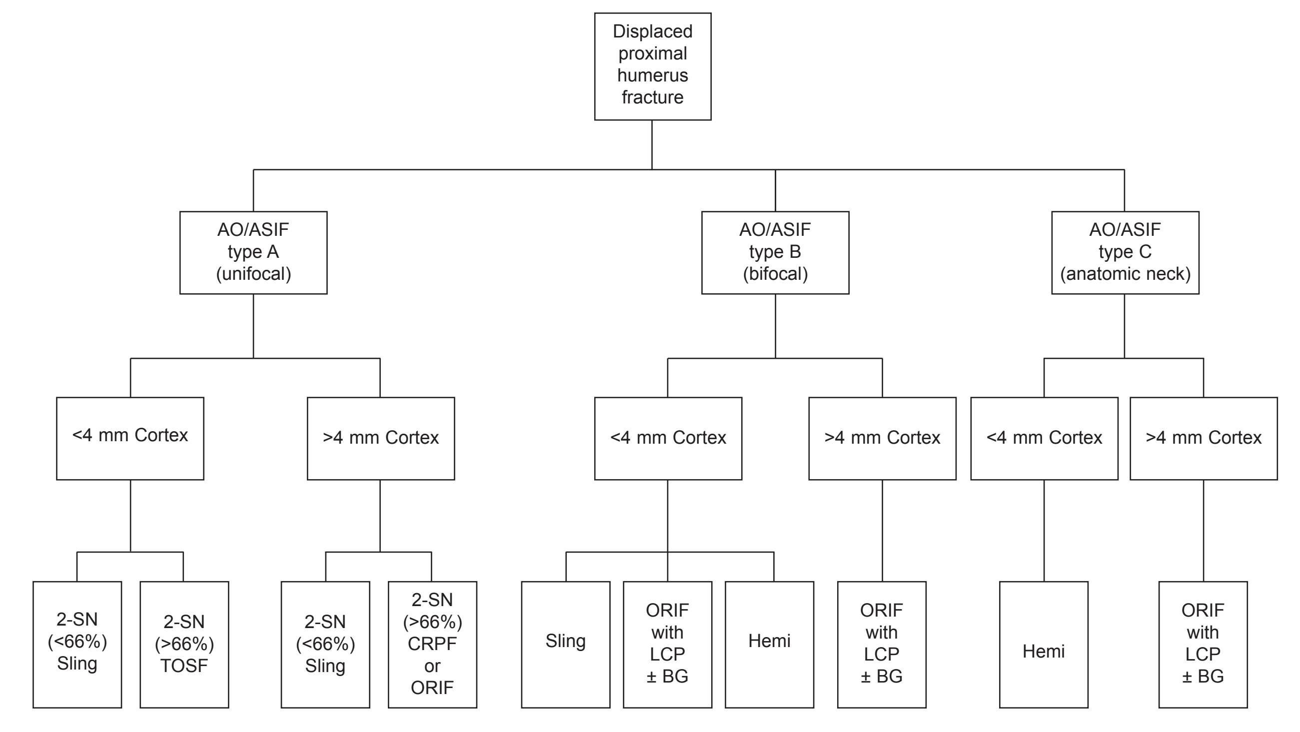
The Neer classification[4] and the AO/ASIF classification[23] are the most widely used systems to evaluate and determine treatment of proximal humeral fractures. The Neer classification is based on the number of fracture parts (displacement >1 cm, angulation >45°), direction of dislocation, and involvement of the articular surface.[4] The AO/ASIF classification system for proximal humerus fractures broadly groups fractures based on the degree of articular involvement and likelihood of vascular injury[23] (Figure 2). Observer reliability and reproducibility for both the Neer and the AO/ASIF classification is fair to poor; it is unlikely that one orthopaedic surgeon will assign the same classification to a proximal humerus fracture at two separate times, just as it is unlikely that two orthopaedic surgeons will agree on a classification. Given these limitations, the AO/ASIF classification for the three basic types of humerus fracture is more user-friendly than the Neer classification,[24] although still complex.

## Treatment Algorithm

Although the management of displaced proximal humerus fractures has evolved toward humeral head preservation, treatment should be guided by careful assessment of vascular status, bone quality, fracture pattern, and degree of comminution, as well as patient factors, such as age and activity level. Patients who are either medically unstable or inactive are poor candidates for surgery and instead may be treated with sling immobilization until the fracture heals. The ultimate goal is maximum shoulder function and minimal shoulder pain. A proposed treatment algorithm (Figure 3) provides a working guideline for the management of proximal humerus fractures, but treatment, whether nonsurgical or surgical, must be individualized according to patient and fracture characteristics.

The likelihood of humeral head osteonecrosis is implicit in the AO/ASIF classification; thus, determining the AO/ASIF fracture type is the initial step in determining the probability of humeral head preservation (Figure 3). Type A is a unifo-

**Figure 3**




Treatment algorithm for proximal humerus fracture. The systematic approach includes assessing vascular status, assigning fracture type using the AO/ASIF classification, assessing bone quality (ie, measure cortex), and applying the Hertel criteria (ie, medial hinge [>2 mm], metaphyseal extension [<8 mm]). 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 = locking compression plate, ORIF = open reduction and internal fixation, TOSF = transosseous suture fixation

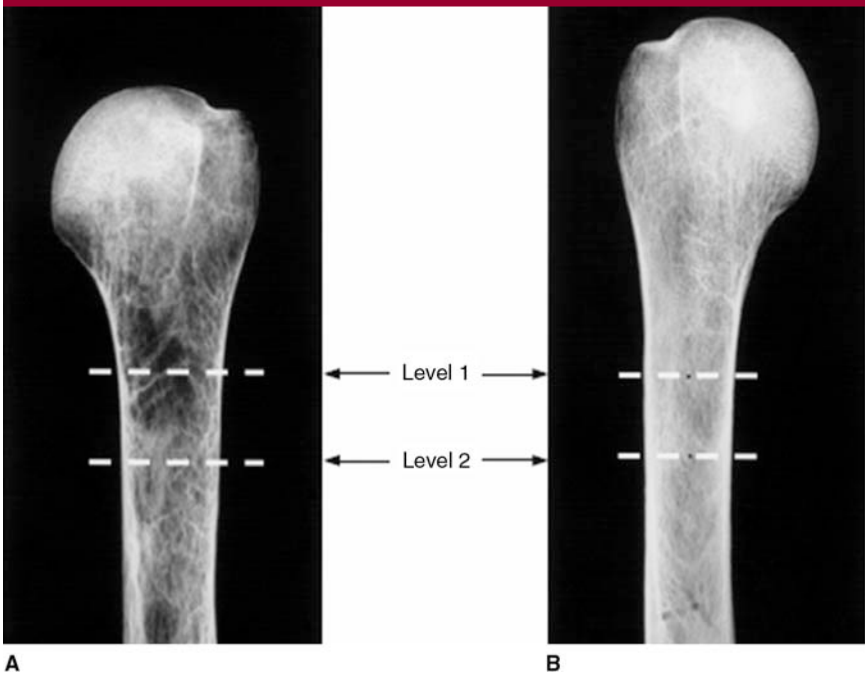
cal, extra-articular fracture with an intact vascular supply. Type B is a bifocal, extra-articular fracture with possible injury to the vascular supply. Type C is an articular fracture involving the anatomic neck with a high likelihood of osteonecrosis.

Cortical thickness of the humeral diaphysis is a more reliable and reproducible predictor of both bone mineral density and the potential for success of internal fixation than is age.[25] After adjusting for magnification, medial and lateral cortical thickness is measured from the anteroposterior view of the proximal humerus.[25] The first level, the most proximal aspect of the humeral diaphysis, occurs at the level in which the endosteal borders of the medial and lateral cortices are parallel. The second level is 20 mm distal to the first level. The combined cortical thickness is the average of the medial and lateral cortical thickness at the two levels[25] (Figure 4). Nonsurgical treatment, suture fixation, and hemiarthroplasty may be the best options for the patient with combined cortical thickness <4 mm. Cortical thickness ≥4 mm is considered necessary for adequate screw purchase with standard internal fixation.[25]

## Nonsurgical Management

Nonsurgical management traditionally has been recommended for nondisplaced and minimally displaced proximal humerus fractures. Sling immobilization with or without closed reduction also has a role in the management of displaced proximal humerus fractures.[3] Court-Brown and colleagues[26,27] recommend 2 weeks of sling immobilization followed by physical therapy for patients with two-part surgical neck fractures[27] and valgus-impacted fractures.[26] Two-part proximal humerus fractures with >66% translation were treated with either a sling or with internal fixation with flexible intramedullary nailing and tension-band wires.[26,27] No statistical difference was reported between the groups in terms of Neer score,[4,28] return to activities of daily living, and fracture union.[26,27] The data demonstrate that the raw Constant score (Table 1) deteriorates with advancing age and degree of displacement. However, when calculated based on age-adjusted Constant score, the

**Figure 4**




Anteroposterior radiographs of the proximal humerus demonstrating the two levels used to measure the combined medial and lateral cortical thickness of the humeral diaphysis. Level one, the most proximal aspect of the humeral diaphysis, occurs at the level in which the endosteal borders of the medial and lateral cortices are parallel. Level two is 20 mm distal to the first level. Examples of patients with low bone mineral density **(A)** and high bone mineral density **(B)**. (Reproduced with permission from Tingart MS, Apprelexa M, von Stechow D, et al: The cortical thickness of the proximal humeral diaphysis predicts bone mineral density of the proximal humerus. *J Bone Joint Surg Br* 2003;85:611-617.)

older patients actually had better scores than did the younger patients.[26,27,29,30] Therefore, sling immobilization is an appropriate treatment option for patients older than age 60 years with valgus-impacted, two-part surgical neck or two-part tuberosity fractures.

## Surgical Management

### Transosseous Suture Fixation

AO/ASIF type A fractures with >66% translation and combined cortical thickness <4 mm are appropriate candidates for suture fixation with tension band constructs. Tension band fixation takes advantage of the soft-tissue anchorage of the rotator cuff tendon, which provides stronger fixation than does the soft bone of the humeral head.[18] Tension band, figure-of-8 constructs incorporating the rotator cuff tendons have proved to be an excellent method of fixation for tuberosity fractures.[18,31] For isolated greater tuberosity fractures with >5 mm of displacement, Flatow et al[32] describe a transosseous suture fixation technique using a lateral approach to the shoulder. Four or five no. 2 nonabsorbable sutures are passed through the supraspinatus tendon, and drill holes are created in the humerus to secure anatomic reduction of the greater tuberosity fragment.

Transosseous suture fixation also can be done on two-part surgical neck fractures and three-part proximal humerus fractures.[32-34] Three no. 2 or no. 5 nonabsorbable sutures are inserted into the supraspinatus and subscapularis tendons to obtain control of the head fragment. The head is reduced over the humeral shaft, and drill holes are made on either side of the bicipital groove to reapproximate the head to the shaft (Figure 5). With a three-part fracture, in order to stabilize the greater tuberosity fragment, the sutures in the fragment are passed through transosseous humeral shaft drill holes after the head is reduced to the shaft and the rotator interval is closed. Several studies report similarly good clinical results in two-part, three-part, and valgus-impacted proximal humerus fractures, as well as a low rate of complications, including osteonecrosis.[19,32,34]

### Closed Reduction and Percutaneous Fixation

Closed reduction and percutaneous fixation with either threaded pins or screws is a reasonable option in AO/ASIF type A (unifocal) fractures with translation >66% and combined cortical thickness >4 mm. The advantage of closed reduction with percutaneous fixation is that it requires minimal surgical dissection with less disruption of the remaining vascular supply. Adequate cortical purchase is required; thus, osteoporotic bone with extensive comminution is a relative contraindication.

Using fluoroscopy, an indirect closed reduction is performed. If necessary, a pointed hook retractor can be introduced into the subacromial space to assist in the reduction. Two to three threaded Kirschner pins (0.045 to 0.0625 in) engage the lateral cortex distal to the deltoid insertion and then are advanced into the subchondral bone of the humeral head without penetrating the articular surface. For greater tuberosity fractures in isolation or in conjunction with surgical neck fracture, two pins should purchase the medial cortex >20 mm distal to the

**Table 1**

**Constant Score**[29]

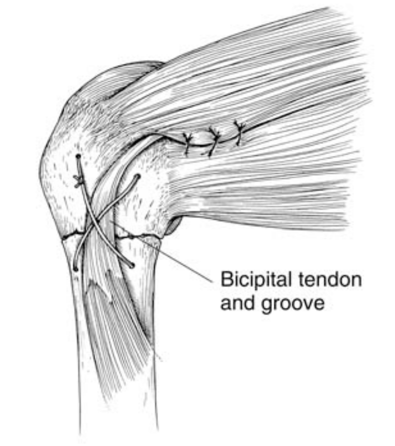
| Subjective Shoulder Assessment (35 total points) | |
|---|---|
| Criteria | Points |
| Pain (15 points) | |
| None | 15 |
| Mild | 10 |
| Moderate | 5 |
| Severe | 0 |
| Activities of daily living (10 points) | |
| Ability to work | 0-4 |
| Ability to engage in recreational activities | 0-4 |
| Ability to sleep | 0-2 |
| Ability to work at a specific level (10 points) | |
| Waist | 2 |
| Chest | 4 |
| Neck | 6 |
| Head | 8 |
| Above head | 10 |

| Objective Shoulder Assessment (65 points) | |
|---|---|
| Criteria | Points |
| Flexion and abduction (scored separately) | |
| >150° | 10 |
| 121°-150° | 8 |
| 91°-120° | 6 |
| 61°-90° | 4 |
| 31°-60° | 2 |
| 0°-30° | 0 |
| Combined active external rotation (10 points) | |
| Hand behind head, elbow forward | 2 |
| Hand behind head, elbow back | 2 |
| Hand on top of head, elbow forward | 2 |
| Hand on top of head, elbow back | 2 |
| Full elevation from top of head | 2 |
| Combined active internal rotation (10 points) | |
| Interscapular region | 10 |
| Inferior tip of scapula | 8 |
| Twelfth rib | 6 |
| Lumbosacral junction | 4 |
| Buttock | 2 |
| Lateral thigh | 0 |
| Strength (25 points) | 1/lb |

inferior border of the head. However, if anatomic reduction cannot be obtained with indirect reduction maneuvers, the surgeon should have a low threshold for converting to open reduction techniques.

Pendulum exercises may be initiated after surgery, and serial radiographs should be taken weekly to ensure that the pins have not migrated. The pins may be removed 6 to 8 weeks later once fracture union is present, at which time active and active-assisted ROM exercises are begun. Good clinical results and low rates of osteonecrosis have been achieved with closed reduction and percutaneous fixation in three- and four-part fractures, even though these fractures are technically more demanding than two-part fractures[11] (Table 2).

**Figure 5**




Transosseous suture fixation for AO/ASIF type A extra-articular, proximal humerus fracture with <4 mm combined cortical thickness. The tension-band construct with transosseous suture fixation can be used for type A fractures involving the surgical neck, greater tuberosity, and lesser tuberosity. (Reproduced with permission from Flatow EL, Cuomo F, Macky MG, et al: Open reduction and internal fixation of two-part displaced fractures of the greater tuberosity of the proximal part of the humerus. *J Bone Joint Surg Am* 1991;73: 1213-1218.)

## Open Reduction and Internal Fixation

### Conventional Plate Fixation

Proximal humerus fractures typically occur in elderly patients with osteoporotic bone; thus, successful implant fixation in these fractures must account for the mechanical and biologic aspects of osteoporotic bone. Poor bone mineral density correlates with reduced ability to securely hold conventional plates and screws,[31] making it difficult to achieve sufficient screw torque to

**Table 2**

**Recent Studies on the Treatment of Proximal Humerus Fractures**

| Study | No. of Shoulders | Fracture Pattern (No.) | Treatment | Outcome Score | Complications (No.) |
|---|---|---|---|---|---|
| Court-Brown et al[26] | 125 | Minimal (57), greater tuberosity (19), surgical neck (18), greater tuberosity and surgical neck (31) | Sling | Mean Constant, 71.8<br>Mean Neer, 80.6% good to excellent | NR |
| Chen et al[33] | 19 | Two-part (13), three-part (6) | CRPF | Neer, 84% good to excellent | Painful hardware (1 [6%]), osteonecrosis (0) |
| Resch et al[11] | 27 | Three-part (9), four-part (18) | CRPF | Average Constant, three-part: 85.4 (91%)<br>Average Constant, four-part: 82.5 (87%) | Osteonecrosis in four-part (2 [11%]) |
| Park et al[34] | 28 | Greater tuberosity (13), surgical neck (9), greater tuberosity and surgical neck (6) | TOSF | Average ASES, 87.1<br>Average Neer, 78% excellent, 11% satisfactory, 11% unsatisfactory | Second surgery (2 [7%]: 1 irrigation and débridement, 1 capsulotomy), osteonecrosis (0) |
| Gerber et al[7] | 34 | Two-part (2), three-part (16), four-part (16) | Internal fixation (CRPF, TOSF, ORIF) ± bone graft | Mean Constant for all shoulders, 78 (89%)<br>Constant without osteonecrosis, 83 (96%)<br>Constant with osteonecrosis, 66 (76%) ($P < 0.0005$) | Osteonecrosis (12 [35%]), malunion (4 [12%]), arthroplasty (2 [6%], second surgery (6 [18%]: 4 SAD, 1 hematoma evacuation, 1 capsulotomy) |

ASES = American Shoulder and Elbow Surgeons, CRPF = closed reduction and percutaneous fixation, NR = not reported, ORIF = open reduction and internal fixation, SAD = subacromial decompression, TOSF = transosseous suture fixation

prevent plate and fracture motion.[37] Screw loosening and pull-out, not implant breakage, is the reason for construct failure and related poor clinical outcomes.[5,33] Furthermore, with extensive comminution, particularly in valgus-impacted fractures, using conventional screws to lag the fracture fragments to the plate typically results in malreduction. Conventional plate-and-screw fixation of displaced proximal humerus fractures has historically been associated with osteonecrosis, nonunion, malunion, screw cutout, and screw loosening.[7]

In young patients, open reduction and internal fixation with buttress plate fixation is appropriate for multifragmentary fractures (ie, AO/ASIF type B). The goal of buttress plate fixation is anatomic reduction, which typically can be accomplished in fractures with an adequate diaphyseal cortex (>3.5 mm) and no metaphyseal comminution.[7] Disruption of the medial hinge is a relative contraindication to the use of buttress plate fixation.[22] Buttress plate application requires extensive soft-tissue dissection, resulting in an increased risk of disruption of the intraosseous blood supply, which predisposes the patient to osteonecrosis. In older, osteoporotic patients, reported rates of osteonecrosis may be as high as 35% with open reduction and internal fixation with plate fixation.[7,35] Although patients treated with conventional plate fixation may have satisfactory clinical results even when osteonecrosis develops,[7,35] patients without humeral head necrosis have significantly ($P < 0.0005$) better clinical outcomes than do patients in whom necrosis develops.[7]

Plates should not be used to bridge gaps in osteoporotic bone; however, double-plating on the opposite cortex may be a reasonable alternative for stabilizing such gaps.[5]

**Table 2 (continued)**

| Study | No. of Shoulders | Fracture Pattern (No.) | Treatment | Outcome Score | Complications (No.) |
|---|---|---|---|---|---|
| Wijgman et al[35] | 60 | Three- and four-part | ORIF with cerclage wires or T-plate | Constant, 87% good or excellent, 13% poor | Osteonecrosis (22 [37%]: 17 [77%] had good or excellent Constant score) |
| Hessmann et al[36] | 98 | Two-part (50), three-part (37), four-part (6) | ORIF with T-plate ± bone cement or bone graft | Constant, 69% good to excellent<br>Neer, 59% good to excellent | Malunion (20 [20%]), osteonecrosis (3 [4%]), nonunion (1 [1%]) |
| Wanner et al[10] | 71 (60 available for follow-up) | Two-part (10), three-part (41), four-part (20) | ORIF with double one-third tubular plate | Mean Constant, 61 (78%) | Complications (7 [12%]): fracture displacement, osteonecrosis, frozen shoulder, SAD, loosening<br>Age and pattern had no effect on outcome |
| Robinson and Page[9] | 25 | Valgus impacted | Screws with Norian Skeletal Repair System, or buttress plate with Norian Skeletal Repair System | Constant (median), 80<br>Dash (median), 22 | Impingement (3 [12%]), wound infection (2 [8%]), adhesive capsulitis (1 [4%]), osteonecrosis (0) |
| Fankhauser et al[6] | 29 | AO type A (4), type B (15), type C (9) | ORIF with locking plate | Mean Constant (all shoulders), 74.6<br>Type A, 82.6<br>Type B, 78.3<br>Type C, 64.6 | Redislocation (4 [14%]), varus malunion (1 screw cutout; 2 impingement) (3 [10%]), partial osteonecrosis (2 [7%]), plate breakage (1 [3%]), deep infection (1 [3%]) |

ASES = American Shoulder and Elbow Surgeons, CRPF = closed reduction and percutaneous fixation, NR = not reported, ORIF = open reduction and internal fixation, SAD = subacromial decompression, TOSF = transosseous suture fixation

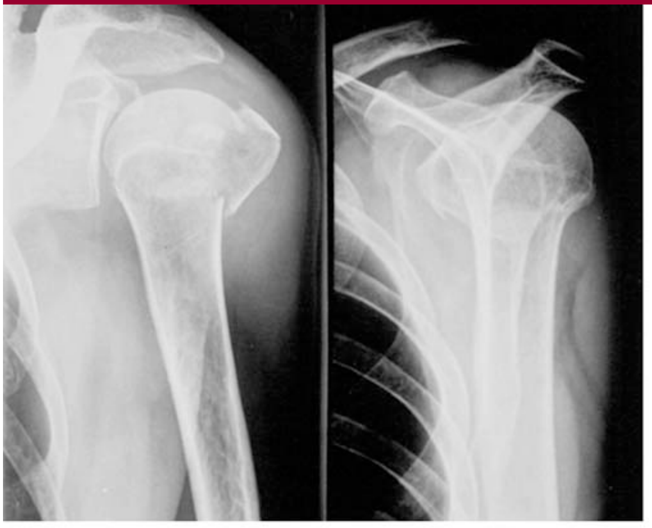
Wanner et al[10] managed 60 shoulders with one-third tubular plates fixed orthogonally on the anterior and lateral cortices (Figure 6). Sixty-three percent of patients had good or very good results. Seven patients (12%) experienced complications, including fracture displacement, osteonecrosis, adhesive capsulitis, subacromial impingement, and hardware loosening.[10]

## Locking Plate Fixation

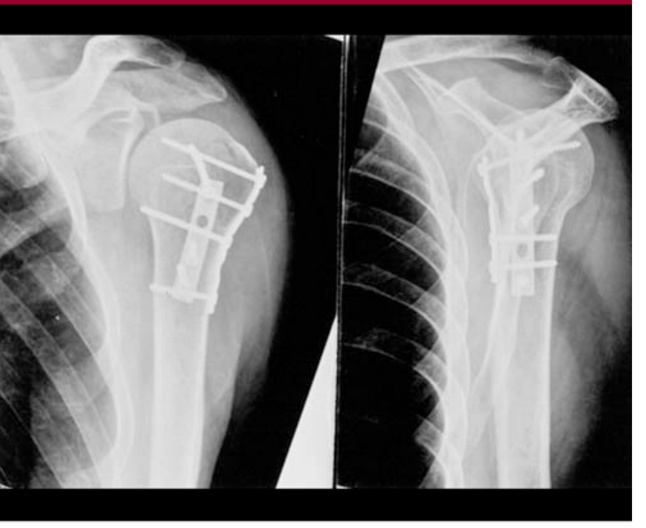
Locking plate technology has been developed as a potential solution to the difficulties encountered using conventional plating to treat fractures in osteoporotic bone, particularly with metaphyseal comminution. The key to this technology is the fixed-angle relationship between the screws and plate. The threaded screw heads are locked into the threaded plate holes to prevent screw toggle, slide, and pull-out, thus diminishing the possibility of primary or secondary loss of reduction.[38] The load is transmitted from the bone to the plate via the screw-plate threaded connection. Because the plate and screws form a single stable system, the stability of the fracture depends on the stiffness of the entire construct.[38] Analogous to multiple, small blade plates,[8] several long metaphyseal screws locked to the plate perpendicular to the limb axis are better able to resist cantilever bending forces and torsional forces.[8] Precontoured, fixed-angle plate designs likely provide a mechanical advantage in fractures with metaphyseal comminution that lack bony contact opposite the plate.[8]

For AO/ASIF type B (bifocal) and type C (anatomic neck) proximal humerus fractures, humeral head preservation may be accomplished with the contoured proximal humerus locking compression plate[6,12] and, when necessary, bone graft or bone

Figure 6



A



B

Open reduction and internal fixation of four-part (AO/ASIF type B) proximal humerus fracture with double, one-third tubular plates. **A,** Anteroposterior (*left*) and scapular-Y (*right*) injury radiographs demonstrating four-part proximal humerus fracture. **B,** Postoperative anteroposterior (*left*) and scapular-Y (*right*) radiographs following placement of one-third tubular plates on the lateral and anterior cortices of the proximal humerus. (Reproduced with permission from Wanner GA, Wanner-Schmid E, Romero J, et al: Internal fixation of displaced proximal humeral fractures with two one-third tubular plates. *J Trauma* 2003;54:536-544.)

graft substitute.[7,9,39] Open reduction and locked plate fixation is contraindicated in some fracture-dislocation patterns, head-splitting fractures, and impression fractures involving >40% to 50% of the articular surface.[15,40,41]

## Surgical Technique

The patient may be positioned in the lateral decubitus position, supine on a radiolucent table, or in the beach chair position. We prefer to place the patient in the beach chair position and to use a standard deltopectoral approach. The anterior one third of the deltoid is dissected off its insertion into the deltoid tubercle. When necessary, the greater and lesser tuberosity fragments are tagged with 5-0 braided, nonabsorbable suture. For three- and four-part fractures, the tuberosity fragments are reduced to the lateral cortex of the shaft. Reduction of the tuberosities may indirectly reduce the head fragment; alternatively, to restore the medial calcar of the proximal humerus, an elevator can be inserted to disimpact the head fragment. The fracture must be reduced and provisionally fixed into position before permanent fixation with the contoured proximal humerus locking plate.

The tagged sutures are passed through the proximal humerus plate, and the plate is positioned directly in the middle of the lateral cortex (Figure 7, A). On the anteroposterior view, the plate should be positioned roughly 8 mm distal to the superior tip of the greater tuberosity; from the lateral view, the plate should be centered against the lateral aspect of the greater tuberosity (Figure 7, B). An adequate gap should be left between the plate and the biceps tendon to prevent disruption of the anterior humeral circumflex artery. The initial screw is placed in the elongated hole in the humeral shaft so that the height of the plate can be adjusted. Once appropriate fracture reduction and plate position have been achieved, the locked screws are inserted into the humeral head using the insertion guide and sleeve assembly. At least three distal shaft screws are inserted. The final fluoroscopic images should demonstrate anatomic reduction of the proximal humerus fracture (Figure 7, C and D).

## Results

Fankhauser et al[6] reported the first series of patients treated with proximal humerus locking plates. Twenty-nine shoulders with proximal humerus fractures (5 AO/ASIF type A, 15 type B, 9 type C) were evaluated at minimum 1-year follow-up using Constant scores and plain radiographs. Mean Constant score for all patients at 1 year was 74.6 (type A, 82.6; type B, 78.3; type C, 64.6). Four patients had redislocation; one fracture was associated with a deep infection. Three patients had varus malunion in which the screws cut through the humeral head; in two of these patients, subacromial impingement developed because the plate was positioned too proximal.

Only 2 of the 29 patients in the study had partial osteonecrosis of the humeral head. In one patient, the plate fractured before fracture healing, necessitating revision surgery.[6]

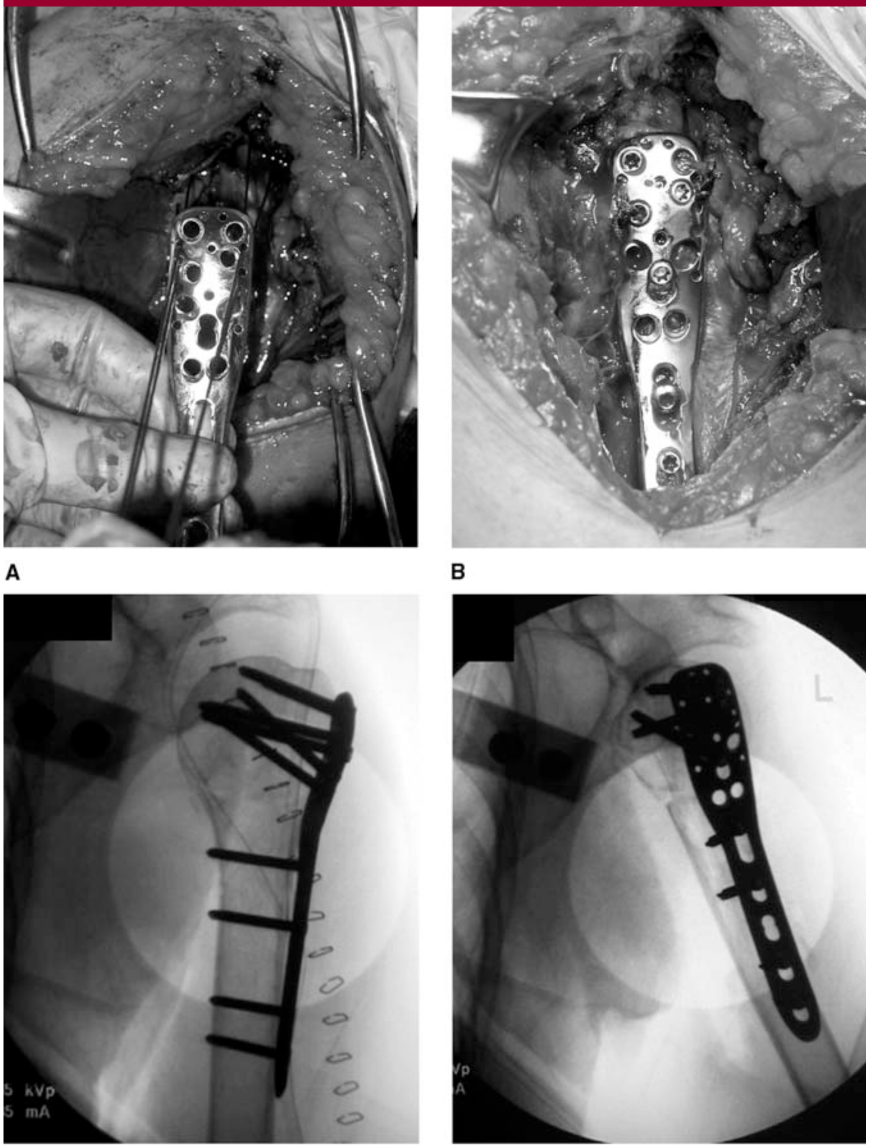
Strohm et al[12] reported 64% good and very good results in 35 patients treated with the proximal humerus locking plate. Partial humeral head necrosis was noted in 16% of patients. The authors reported that some patients have a high risk of proximal screw perforation of the humeral head. Although preliminary results are promising with locking plates, additional studies with larger cohorts and longer follow-up are necessary to better define the appropriate indications for and expected outcomes with this technology.

## Osteobiologics

Displaced proximal humerus fractures may have significant metaphyseal comminution, which often is more apparent after anatomic reduction of fracture fragments. Bone graft or bone graft substitute may be used as a local adjuvant to fracture healing. The indications have not yet been clearly defined, but improved rates of fracture healing and decreased rates of malunion have been reported.[7,36] Autogenous bone graft, which has been shown to have osteoinductive, osteoconductive, and osteogenic[31] properties, can stimulate new bone formation in metaphyseal defects associated with complex proximal humerus fractures. Elderly, osteoporotic patients have limited quantity and quality of available iliac crest graft, necessitating larger exposure, thus placing them at risk of increased complications associated with a second surgical site.[5]

Bone graft substitutes are an attractive alternative, particularly in osteoporotic patients. Substitutes include synthetic osteoconductive materials, allograft bone, and demineralized allograft bone matrix.[5,7,36]

**Figure 7**



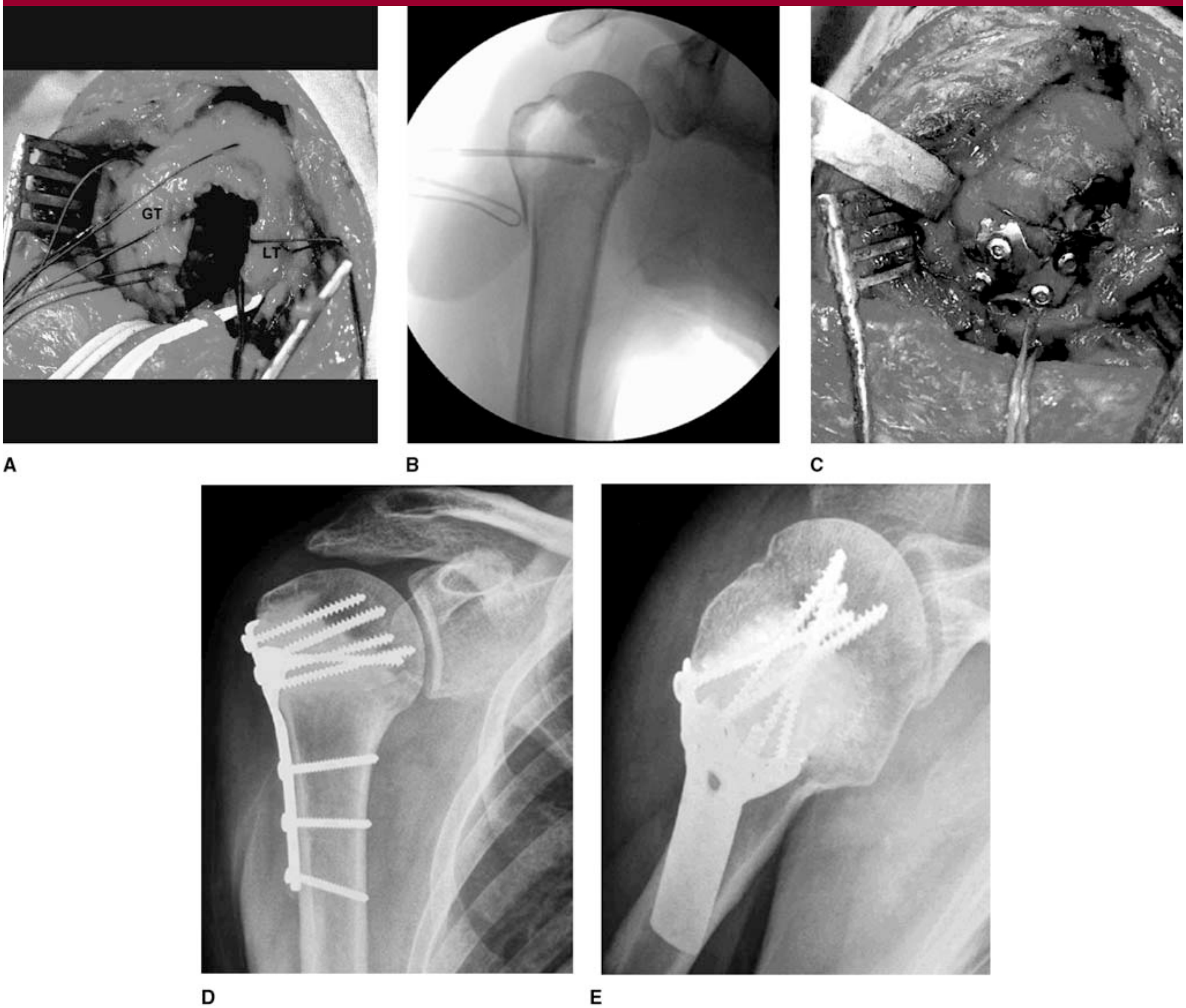
A B C D

Treatment of AO/ASIF type B proximal humerus fracture with locked plate fixation. **A,** Tagged sutures are passed through the proximal humerus locking plate. **B,** Locked plate on the lateral cortex with suture fixation to the plate. Anteroposterior **(C)** and internal rotation **(D)** radiographs demonstrating anatomic reduction after open reduction and internal fixation with a proximal humerus locking plate.

Calcium phosphate cements (eg, Norian Skeletal Repair System, Synthes, West Chester, PA; Alpha BSM, Etex, Cambridge, MA) can be injected or molded into small bone defects; they provide structural support with good compressive strengths.[42] Using the Skeletal Repair System, Robinson and Page[9,39] achieved osseous union without evidence of osteonecrosis in all fractures, and the average head-neck inclination remained within previously published normal values[9] (Figure 8).

The disadvantages of calcium phosphate cements are poor shear strength, slow resorption, and complete lack of osteoinductivity.[42] For

**Figure 8**




Use of the Norian Skeletal Repair System (Synthes) to repair metaphyseal defects in the humeral head. **A**, After provisional fixation of the fracture and tagged tuberosity sutures, the metaphyseal defect is evident between the articular fragment and the tuberosity fragments. **B,** Fluoroscopic image demonstrating the area of radiolucency after anatomic reduction. **C,** The metaphyseal cavity is closed by suturing together the tuberosity fragments. Anteroposterior **(D)** and modified axial **(E)** radiographs demonstrating anatomic reduction after open reduction and internal fixation and use of the Norian Skeletal Repair System (the radiodense area behind the humeral head). GT = greater tuberosity, LT = lesser tuberosity. (Reproduced with permission from Robinson CM, Page RS: Severely impacted valgus proximal humeral fractures. *J Bone Joint Surg Am* 2004; 86[suppl 1 pt 2]:143-155.)

larger metaphyseal defects (>20 mL volume), structural allograft, morcellized allograft, or autograft may be used to fill the void.[39] Demineralized human bone matrix can enhance structural integrity and has variable osteoinductive properties; however, as with other allografts, there are risks, including unpredictable quality and the possibility (however slight) of disease transmission.[42] Bone graft substitute in conjunction with locked plate fixation has not yet been studied, and its effect on fracture union and malunion is unknown.

## Hemiarthroplasty

Traditionally, the indications for hemiarthroplasty in the management of proximal humerus fractures are four-part fractures, three-part fractures in older patients with osteoporotic bone, fracture-dislocations, head-splitting fractures, and impression fractures involving >40% to 50% of the articular surface.[15,40,41] The tenuous fixation of fracture fragments in osteoporotic bone[15] and the high rates of osteonecrosis in the humeral head after three- or four-part fracture suggest that hemiarthroplasty is a better treatment alternative for these fracture patterns. Although hemiarthroplasty has been shown to provide good pain relief, achieving excellent ROM has been less predictable. Rehabilitation, particularly early passive ROM[43,44] and long-term active ROM and strengthening, is considered essential to achieve optimal outcome after shoulder hemiarthroplasty.[43,45] In recent studies, the results of hemiarthroplasty for proximal humerus fractures have been reasonable, although not quite as good as the results in earlier studies.[15,41,43-48]

## Surgical Technique

Shoulder hemiarthroplasty technique is well-described in the literature. Typically, a standard deltopectoral approach 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 tuberosity fragments. The humeral head and shaft fragments are exposed; the glenoid should be carefully inspected to determine whether a glenoid component is warranted. After adequately exposing and cleaning the joint, preparation of the humeral shaft begins. It is critical to place the humeral component in the correct retroversion (typically 30° to 40°) and height. Different modular heads can be trialed to identify the optimal configuration. With most fractures, the stem should be cemented to ensure rotational control of the prosthesis. Once the humeral component is secure, the proximal anatomy is restored, with particular emphasis on correct, secure positioning of the tuberosities through a variety of suturing techniques. Bone graft may be necessary. The shoulder should be taken through a ROM before closing.

## Results

Recent studies have focused on maximizing tuberosity healing in an anatomic position and optimizing the degree of component retroversion.[43,49] Most authors recommend 30° to 40° of retroversion, typically using the bicipital groove as the landmark for prosthesis orientation.[49] However, an individualized approach has been proposed, in which the contralateral humerus is used to estimate the proper retroversion for each patient.[43] A recent study found no difference in terms of mean Constant score when comparing patients treated with these different techniques for achieving proper version, although the sample size (26 patients) and resulting statistical significance were limited.[43]

Complications after hemiarthroplasty include tuberosity malunion or nonunion, heterotopic ossification, degenerative changes in the glenoid, prosthetic loosening, and nerve injury. Malunion or nonunion of tuberosity osteosynthesis occurs in 4% to 50% of shoulders and is the most significant complication after hemiarthroplasty for displaced proximal humerus fractures.[40,45,47] In one study, the factors that led to tuberosity malunion were poor intraoperative positioning of the prosthesis (excessive height and/or retroversion), age and sex (women older than age 75 years), and initial malposition of the greater tuberosity.[47]

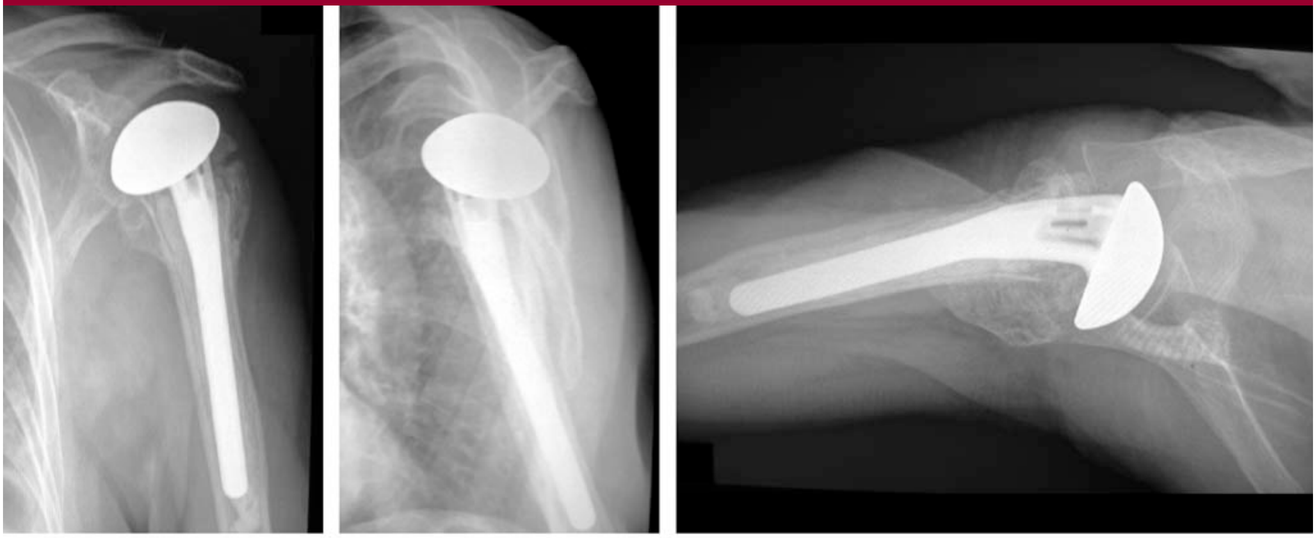
Boileau et al[47] reported an 11% rate of heterotopic ossification, similar to the rate reported by Prakash et al[45] (9%), but lower than that reported by Mighell et al[41] (27%) and Becker et al[46] (56%). Mighell et al[41] reported an 8% rate of degenerative changes in the glenoid at 36-month average follow-up. A recent quantitative radiographic analysis of glenoid wear after shoulder hemiarthroplasty found a decrease in average joint space from 2.9 to 1 mm over a mean 43-month period in eight patients.[50] The data suggest that functional outcome, as measured by Constant score, negatively correlated with joint space narrowing.[50]

Prosthetic loosening occurs less often, with reported rates of 3% to 6%,[43,45] although higher rates of radiolucencies (30%) have been reported.[47] Infection usually occurs at an even lower rate, typically 1% to 2%,[41,48] although one study reported a 7.7% rate of infection.[43] Although up to 15% of patients may present preoperatively with nerve injury from the original trauma,[41,43,48] the reported rate of intra- or postoperative nerve injury typically is close to zero.[41,43,45,48] However, one study reported a rate of 4.5%.[47]

Both surgeon and patient must have realistic postoperative expectations for proximal humerus fracture after hemiarthroplasty. Typical end ROM achieves shoulder-level function. Although the mean reported ROM for forward flexion is often above 100°,[41,43,47] only 42% of patients could flex above 90° in the series reported by Kralinger et al.[44] Most studies suggest mean internal rotation to approximately L2/L3,[41,44,45] with mean external rotation typically varying between 20° and 40°.[41,43,44,46,47] Functional results are usually satisfactory, with recent studies showing a mean Constant score between 55 and 70.[43,44,47]

The importance of anatomic restoration of the tuberosities with secure fixation and restoration of humeral length and retroversion cannot be overemphasized (Figure 9). One recent cadaveric study evaluated a design in which the bone-tendon interface of the rotator cuff is fixed to holes in the articular rim of the prosthesis.[51] The fixation was strong enough to resist fracture fragment displacement under the forces associated with activities of daily living, suggesting that this design

Figure 9




Anteroposterior **(A)**, scapular-Y **(B)**, and axillary **(C)** radiographs following shoulder hemiarthroplasty.

might allow earlier rehabilitation even in the presence of poor bone quality. Biomechanical studies have shown that incorporation of medial circumferential cerclage around the tuberosities decreases interfragmentary motion and strain, maximizes fracture stability, and facilitates postoperative rehabilitation.[52]

Postoperative outcomes depend on several variables, chief among them displacement of the tuberosities. Robinson et al[48] retrospectively reviewed the results of shoulder hemiarthroplasty for proximal humerus fractures at a single center. They found consistent improvement in the Constant score from 6 weeks to 6 months postoperatively but little change thereafter. At 1 year, patients reported reasonable pain relief but poorer scores for function, ROM, and strength. The factors assessed 6 weeks postoperatively that predicted 1-year Constant score included patient age, persistent neurologic deficit, need for early revision, as well as the degree of displacement of the prosthetic head from the central axis of the glenoid and the degree of displacement of the tuberosities (seen radiographically).

In their retrospective multicenter review, Kralinger et al[44] ($P = 0.0001$) found that patients with healed, nondisplaced tuberosities had significantly higher Constant scores and subjective patient satisfaction scores ($P = 0.031$) than did patients whose tuberosities did not heal or healed in displacement >0.5 cm. However, pain did not correlate with displacement of the tuberosity. Although Coleman and Craig[53] also reported no difference in overall pain score between patients with a healed greater tuberosity and those without, their retrospective review did find greater forward flexion and external rotation in patients with a healed greater tuberosity. In a retrospective review of the results of a single surgeon, Mighell et al[41] found significantly lower ASES ($P < 0.01$) and Simple Shoulder Test ($P < 0.001$) scores as well as decreased forward flexion in patients with superior migration of the greater tuberosity.

The optimal timing of hemiarthroplasty is important—specifically, acute versus late reconstruction. Because it is technically easier, acute treatment is generally preferable to later hemiarthroplasty. Most recent reports tend to show better results after early treatment,[41,46] although one study found no difference between early (≤30 days postinjury) and late (>30 days postinjury) treatment.[45] A series of 27 displaced four-fragment fractures of the proximal humerus treated with hemiarthroplasty showed better shoulder motion (measured by video motion analysis) and better clinical outcomes (Neer and Constant scores) when treated within 2 weeks of injury, compared with those treated later.[46] Mighell et al[41] found significantly ($P < 0.01$) greater ASES scores in patients treated within 2 weeks of initial injury. Prakash et al[45] did not find any difference in final ROM between patients who underwent surgery within 30 days of initial injury and patients who underwent surgery more than 30 days after injury, even though the mean time from injury to surgery among the latter group was 13 months.

## Summary

Proximal humerus fracture management is constantly evolving, particularly in light of improved understanding of proximal humerus fracture characteristics and innovations in surgical technique and technology. The orthopaedic surgeon should approach proximal humerus fractures on a case-by-case basis and tailor treatment according to patient and fracture characteristics. Treatment decision-making should include assessing the vascular status of the humeral head, determining the optimal fixation constructs, and implementing local adjuvants as needed to enhance anatomic fracture healing. The likelihood of humeral head ischemia is established using the AO/ASIF classification and Hertel's radiographic criteria. Fractures with AO/ASIF type C pattern, metaphyseal extension <8 mm, or medial hinge displacement >2 mm are associated with high probability of osteonecrosis and probably are best treated with hemiarthroplasty.

When fixation is required, fracture pattern and cortical thickness should guide the treatment approach and fixation technique. AO/ASIF type A fractures are typically treated with sling immobilization. Proximal humerus fractures with surgical neck translation >66% or tuberosity displacement >5 mm may be treated with transosseous suture fixation (cortex <4 mm) or closed reduction and percutaneous fixation (cortex >4 mm). For multifragment fractures, locked compression plating creates a stable construct with preservation of the periosteal blood supply. Calcium phosphate cement, demineralized bone matrix, and allografts are important local adjuvants that may improve rates of osseous union and minimize malunion. Given recent developments in locking plate and osteobiologics technology, the most relevant question may be whether open reduction and internal fixation will in future produce better results than hemiarthroplasty and, if so, in which patients.

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*Evidence-based Medicine:* There are no level I or II randomized prospective studies referenced. The majority of references are observational cohort or case control studies (level III/IV) or expert opinion (level V).

Citation numbers printed in **bold type** indicate references published within the past 5 years.


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