Displaced Proximal Humeral Fractures: Evaluation and Treatment

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Abstract

Successful treatment of proximal humeral fractures relies on the surgeon's ability to make an accurate diagnosis. Treatment must be predicated on a thorough understanding of the complex shoulder anatomy, a precise radiographic evaluation, and use of a well-designed classification system. Appropriate and realistic goals must be established for each patient. The patient's general medical health, physiologic age, and ability to cooperate with intense and prolonged rehabilitation are all considerations when selecting the optimal treatment.

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The majority of patients who sustain proximal humeral fractures are in the middle and older age groups.[1-3] In younger patients these fractures are often the result of high-energy injuries. Osteoporosis plays a significant role in the older sedentary patient.[4,5] The proximal humerus becomes more susceptible to fracture with age because of the structural changes that occur with senescence.[6]

Eighty-five percent of proximal humeral fractures are minimally displaced or nondisplaced and can be effectively treated with early functional exercises. In the remaining 15%—displaced proximal humeral fractures—the knowledge and skill of the surgeon will in part determine the functional outcome. Knowledge of the bony architecture, the effect of muscle action, and the blood supply underlie successful classification and treatment of these injuries. Neer's classification and treatment scheme for displaced proximal humeral fractures[1] has greatly facilitated rational management.

Anatomy

Bones

The proximal humerus consists of four well-defined parts: the humeral head, the lesser and greater tuberosities, and the proximal humeral shaft. There is a well-defined relationship between these four parts and the neck-shaft inclination angle, which measures an average of 145 degrees in relation to the shaft and is retroverted an average of 30 degrees. The proximal humerus arises from three distinct ossification centers, including one for the humeral head and one each for the lesser and greater tuberosities. The fusion of the ossification centers creates a weakened area, the epiphyseal scar, which makes these regions of the proximal humerus particularly susceptible to fracture.

Rotator Cuff and Girdle Muscles

The rotator cuff and shoulder-girdle muscles create forces on the proximal humerus, which are in equilibrium when the proximal humerus is intact. This balance is disrupted when one or several parts of the proximal humerus are fractured.

The pectoralis major and deltoid muscles exert the most deforming forces on the distal shaft fracture segment, while the proximal fragments, consisting of the articular head segment and the lesser and greater tuberosities, are most deformed by the rotator cuff musculature. Understanding these deforming forces facilitates treatment (Fig. 1).

Blood Vessels

Disruption of the arterial blood supply to the proximal humerus due to trauma or surgical intervention can result in avascular necrosis of the humeral head. There are three main arterial contributions to the proximal humerus (Fig. 2).[7,8] The major arterial contribution to the humeral head segment is the anterior humeral circumflex artery. The terminal portion of this vessel, the arcuate artery, is interosseous and perfuses the entire epiphysis.[7,8] If this vessel is injured, only an anastomosis distal to the lesion can compensate for the resulting loss of blood supply.

Less significant blood supply to the proximal humeral head is derived from a branch of the posterior humeral circumflex artery and from the small vessels entering through the rotator cuff insertions. The posterior humeral circumflex artery, which penetrates the posteromedial

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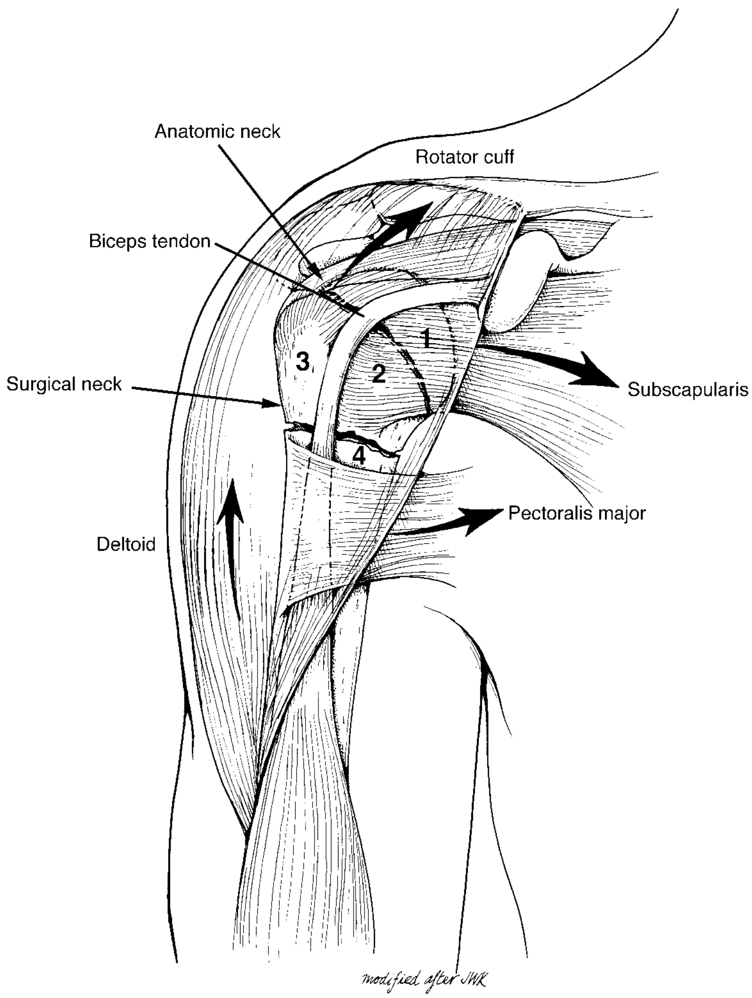


Fig. 1 Displacement of a fracture fragment is due to the pull of muscles attached to the various bony components: the head (1), the lesser tuberosity (2), the greater tuberosity (3), and the shaft (4). The subscapularis inserts on the lesser tuberosity; its unopposed pull causes medial displacement. The supraspinatus and infraspinatus insert on the greater tuberosity; unopposed pull can cause superior and posterior displacement. The pectoralis major inserts on the humeral shaft; its unopposed pull can cause medial displacement.

cortex of the humeral head, supplies only a small portion of the posteroinferior part of the articular surface of the humerus compared with the arcuate artery. The vessels that enter the epiphysis via the rotator cuff insertions are also inconsequential, as well as inconsistent in their vascular supply to the humeral head.

Classification

A functional classification system provides the means for an accurate and reproducible diagnosis, facilitates communication, and directs treatment. The system must be sufficiently comprehensive to encompass all these factors, yet specific enough to lead to accurate diagnosis and treatment.[9] A number of classification systems have been proposed to accomplish these goals, based on the anatomic level of the fracture, mechanism of injury, amount of contact by fracture fragments, degree of displacement, and / or vascular status of the articular segment.[10,11] However, these systems have not proved useful in diagnosis and treatment of the more complex fracture patterns.

In 1970, Neer[1] devised a classification scheme based on the displacement of the four proximal humeral segments. He later eliminated his numeric groupings and detailed the application of the simplified version referring only to the segments involved. In this system, a segment is considered to be displaced if it is separated from its neighboring segment by more than 1 cm or is angled more than 45 degrees from its anatomic position. The fracture pattern refers to the number of displaced segments (i.e., two-part, three-part, or four-part). The number of fracture fragments or lines is considered irrelevant unless it fits into the previously described classification. Although Neer's system does not consider all the various

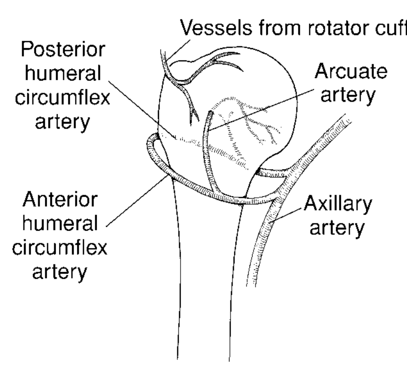


Fig. 2 Blood supply of the proximal humerus.

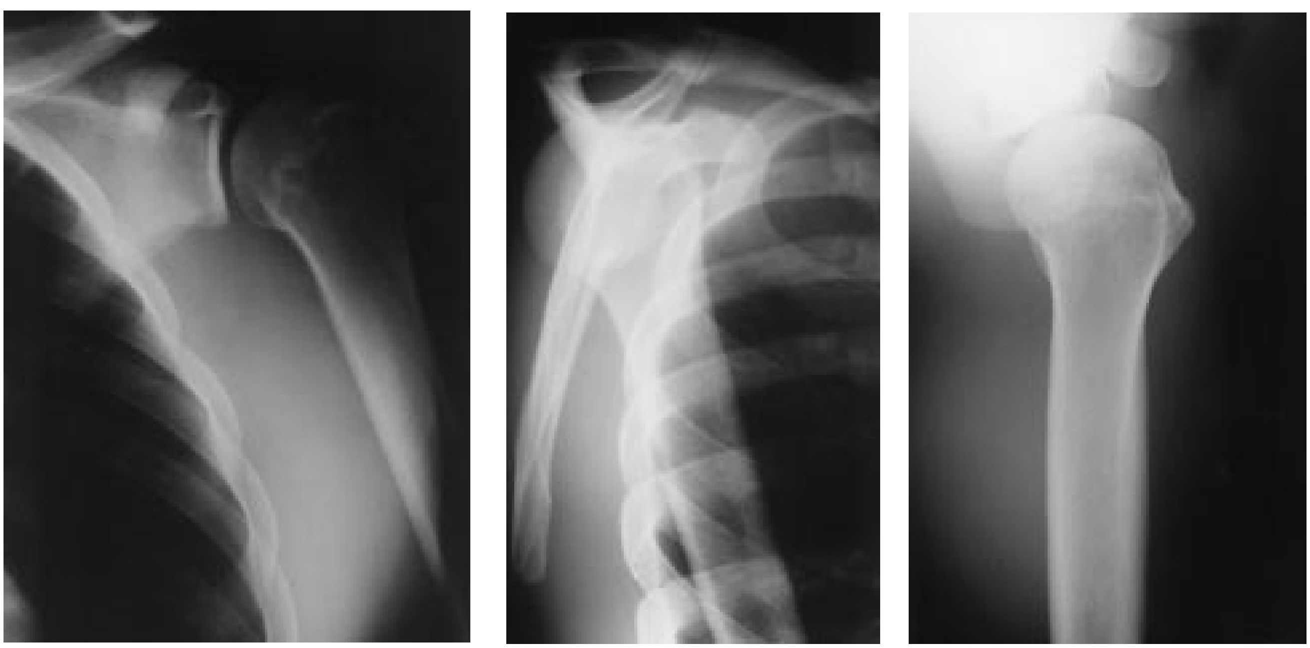
fracture subpatterns that can affect treatment, it remains the accepted standardized classification, at least in North America.

It is important to appreciate that the terminology used to identify proximal humeral fractures denotes first the pattern of displacement and second the key segment displaced. For example, in a three-part pattern, a displaced tuberosity is always considered the key segment even though a displaced shaft segment is also present (e.g., three-part greater-tuberosity displacement). With fracture-dislocations, the fracture pattern is identified first, but the direction of the dislocation replaces the key segment in the description. A fractured tuberosity segment is always displaced in the direction opposite the dislocation. Therefore, a three-part anterior fracture-dislocation would refer to anterior dislocation of the head and attached lesser tuberosity and posterior displacement of the greater tuberosity. The position of the associated displaced shaft segment is variable.

The AO group has proposed an alternative classification scheme, which emphasizes the vascular supply to the articular segment.[12] This system was developed in an attempt to predict the risk of avascular necrosis. Their classification scheme is divided into three categories according to the severity of the injury. Type A represents the least severe fracture, with no vascular interruption to the articular segment and little risk of avascular necrosis. Type B represents a more severe injury accompanied by an increased risk of avascular necrosis. Type C is the most severe fracture, with total vascular isolation of the articular segment and a high risk of avascular necrosis. Each group is then subdivided according to a numeric scheme to further delineate severity. Because the AO classification system is more complicated and has not as yet been shown to predict long-term outcomes of treatment, most surgeons continue to use the Neer system.

Radiographic Evaluation

Accurate diagnosis is essential for optimal treatment of proximal humeral fractures. Three radiographic views are required in most cases to ensure consistent identification of fracture type (Fig. 3). If only two views can be obtained, true anteroposterior and axillary would be ideal for classification. Radiographs of the injured shoulder are taken both perpendicular and parallel to the scapular plane.[13] Although fracture fragments may be shifted with any movement of the patient's arm, we nevertheless advocate an axillary view, best taken in 20 to 40 degrees of abduction, as an essential third view because (1) it contributes valuable additional information about the fracture configuration, since it is oriented at right angles to the two previous



A B C

Fig. 3 Standard radiographic examination of the shoulder. **A,** Anteroposterior view. **B,** Lateral scapular view. **C,** Lateral axillary view.

views; (2) it is the most reliable means of detecting a locked posterior dislocation with an impression fracture; and (3) it provides an assessment of the glenoid margin.

Each of these three views may be obtained with the patient in a standing, sitting, or supine position. If a sling has been applied, it need not be removed. When the patient is too uncomfortable to permit the arm to be abducted, a Velpeau axillary view can be obtained.[13] The patient is seated and tilted obliquely backward 45 degrees, and the radiograph is taken from above.

These three plain radiographs are sufficient to make an accurate diagnosis. On occasion, computed tomography (CT) is helpful in further defining the magnitude of humeral-head defects in head-splitting fractures, impression fractures, and chronic fracture-dislocations. Computed tomographic scans can also be helpful in determining the amount of displacement of greater-tuberosity fractures,[14] as well as in assessing glenoid pathology.

Methods of Treatment

Many methods of treatment of proximal humeral fractures have been proposed. Fortunately, the majority (85%) of proximal humeral fractures are minimally displaced or nondisplaced and therefore can be treated nonoperatively with a sling for comfort and early range-of-motion exercises. The remaining 15% of proximal humeral fractures are the subject of the rest of this review.

Two-Part Anatomic-Neck Fractures

The anatomic neck represents the old epiphyseal plate, whereas the surgical neck represents the weakened area below the tuberosity and head and is approximately 2 cm distal to the anatomic neck.

The two-part anatomic-neck fracture is extremely rare, and insufficient data have been published to suggest the ideal method of management.[12,15] Some authors have recommended an attempt at preserving the fragment, especially if the patient is young. Closed reduction is difficult because the articular-head segment is usually angulated or rotated. Open reduction and internal fixation with interfragmentary screws is an option; however, it is difficult to obtain adequate screw purchase in the small head fragment without violating the articular surface.

Most clinical outcome studies agree that prosthetic hemiarthroplasty provides the most predictable result. A deltopectoral approach with release of the subscapularis tendon from the lesser tuberosity gives excellent exposure. Following removal of the head fragment and reaming of the shaft, the humeral component is implanted at 30 to 40 degrees of retroversion relative to the epicondyles of the elbow. Rehabilitation begins early following surgery and progresses rapidly from assisted to active exercises.

Two-Part Greater-Tuberosity Fractures

Two-part displaced fractures of the greater tuberosity are relatively uncommon. They are often associated with an anterior glenohumeral dislocation. After closed reduction, residual displacement of the greater tuberosity is common (Fig. 4, A). Neer reported that displacement of the fragment by more than 1 cm was pathognomonic of a longitudinal tear of the rotator cuff. In most cases, the greater tuberosity is displaced superiorly and posteriorly by the unopposed pull of the rotator cuff. If the fracture heals in this displaced position, it will cause impingement under the acromion, limiting forward elevation and external rotation.

Radiographic findings can be subtle because of the small size of the fragment. Plain radiographs frequently underestimate the residual posterior displacement, which may be the reason for the low reported incidence of two-part greater-tuberosity fractures. Therefore, CT scans are often warranted to assess the displacement of the fragment.

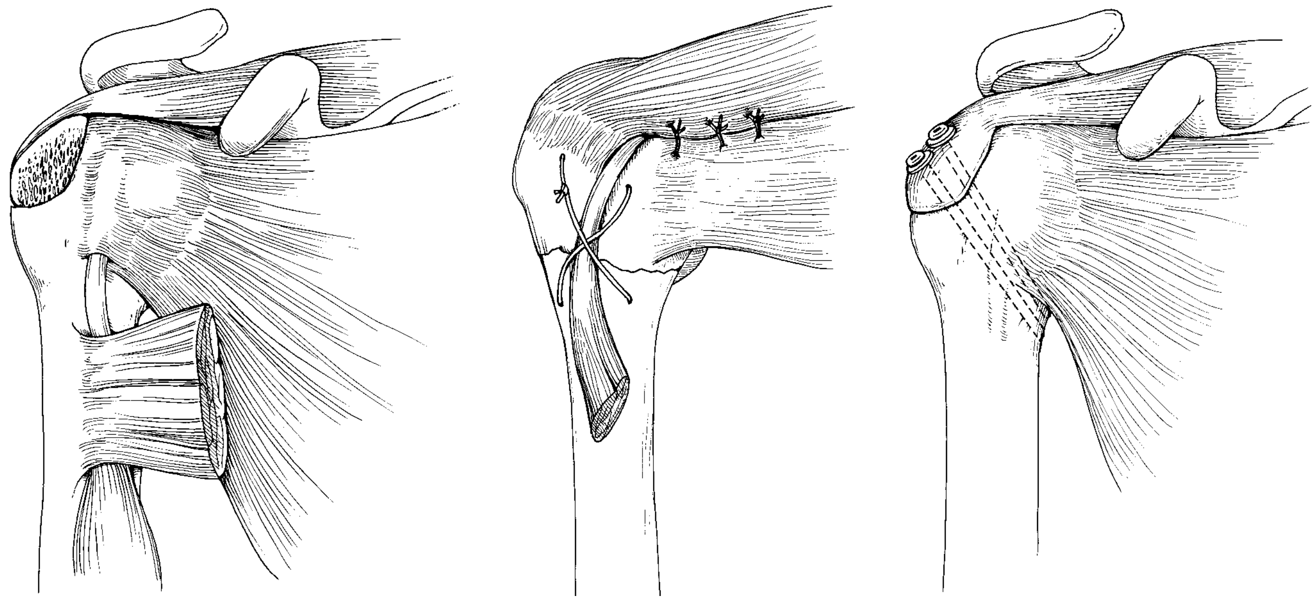
McLaughlin[16] found that outcomes correlated closely with the amount of residual fragment displacement. Patients with fractures that healed with more than 1.0 cm of displacement suffered permanent disability, while those with less than 0.5 cm of displacement did well. With 0.5 to 1.0 cm of displacement, there was often a prolonged convalescence, many patients had persistent pain, and 20% required revision surgery.

Closed reduction of the fracture fragment can be attempted with longitudinal traction, flexion, and adduction of the arm to the neutral position. Even if reduction is obtained, however, the greater tuberosity is liable to later displace. Therefore, serial radiographs are needed to check for subsequent displacement if closed reduction is selected.

Open reduction and internal fixation are recommended in cases with residual displacement greater than 1 cm. Repair with multiple heavy nonabsorbable sutures incorporated into the rotator cuff tendon (Fig. 4, B) has produced favorable results.[17] When the fragment is large enough, the fracture can be stabilized with a screw and washer (Fig. 4, C).[18] In all cases, the rotator cuff tendon should be meticulously repaired.

Two-Part Surgical-Neck Fractures

These fractures occur through the surgical neck and the shaft, which is displaced more than 1 cm and/or angulated more than 45 degrees



A B C

Fig. 4 **A,** Displaced two-part greater-tuberosity fracture. **B,** Figure-of-eight repair with heavy nonabsorbable sutures. **C,** Screw-and-washer fixation.

from its original position. Because both tuberosities are attached to the head, it often remains in a neutral position. A posterior hinge is frequently present, which contributes to the apical anterior angulation of the fracture. If the head fragment is left significantly angulated, limitation of forward elevation may compromise eventual function.

Most displaced two-part surgical-neck fractures are unimpacted, and the shaft is displaced anteromedially by the pull of the pectoralis major (Fig. 5). Although closed reduction may be attempted, repeated and forcible attempts at closed reduction are inadvisable. Reduction may be prevented by interposition of the periosteum, biceps tendon, or deltoid muscle or by buttonholing of the shaft through the deltoid, pectoralis major, or fascia. If the first attempt is unsuccessful, it is usually best to attempt the next reduction with the use of general anesthesia and an image intensifier. Fluoroscopy will allow visualization of the fracture fragments.

The technique of closed reduction involves distal traction and lateral displacement with simultaneous flexion of the shaft. Traction is then released to lock the fragments together. If an acceptable reduction is achieved, sling immobilization for 3 to 4 weeks is adequate. Without fixation, however, angulation often recurs. With closed reduction, it is maintaining, rather than obtaining, the reduction that presents the challenge.

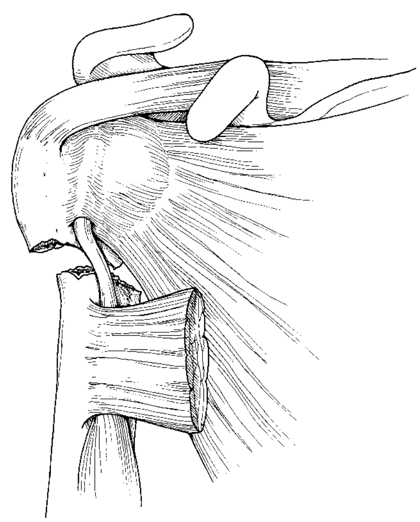


Fig. 5 Displaced two-part surgical-neck fracture.

In many cases, the fracture is reducible but unstable, and percutaneous pin fixation may be used. Under fluoroscopic control, Steinmann pins can be advanced across the reduced fracture from the anterior and lateral cortex of the shaft into the proximal segment (Fig. 6). It is often easier to skewer the head from above through the greater tuberosity adjacent to the acromion, passing the pins into the distal segment. Fixation may not be rigid; therefore, sling immobilization for 3 to 4 weeks is required while the fracture segments become secure. The pins are then removed, and rehabilitation is begun.

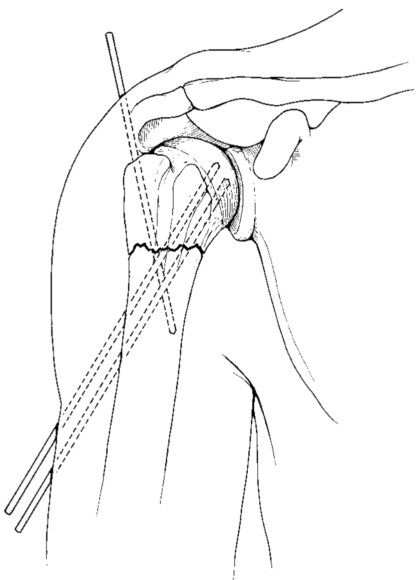


Fig. 6 Percutaneous pinning of a two-part surgical-neck fracture.

In certain cases, a closed reduction may be too difficult to obtain or the reduction of the fracture proves too unstable to be effectively maintained by percutaneous pinning. It may then be necessary to proceed with open reduction and internal fixation. Our preferred method of fixation involves the use of some form of intramedullary fixation in conjunction with the tension-band technique (Fig. 7, A). The tension-band technique is inadequate by itself.[19] However, when the tension-band technique incorporates the rotator cuff tendon and is used in conjunction with intramedullary fixation, adequate stability is achieved. This more secure construct allows for early passive range-of-motion exercises.

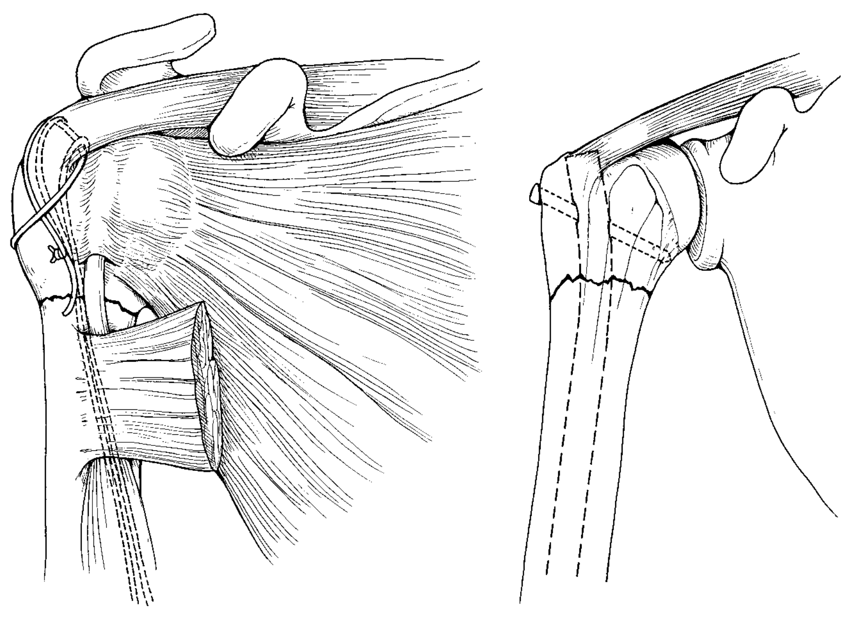
Many other methods of open reduction and internal fixation have been proposed. In young patients with good bone stock, the use of an AO buttress plate and screws has been reported to give good results. Potential complications include loosening of the screws, particularly in osteoporotic patients; impingement of the plate if it is positioned too far proximally; and persistent varus deformity.[18] Screws may also violate the articular surface or limit motion if left protruding laterally.

The use of an intramedullary rod alone is another alternative means of internal fixation. Ender nails or Rush rods can be inserted through a very limited incision, splitting the deltoid and rotator cuff. The disadvantage with this technique is that it may not provide rigid fixation or control for rotational displacement. Additionally, a second surgical procedure is often required to remove the hardware, since it can produce impingement on the undersurface of the acromion. Other intramedullary devices have been developed to provide greater rigidity, as well as rotational control with the use of a proximal interlocking screw (Fig. 7, B). These devices have solved many of the previous difficulties with simple rod fixation. Use of a Mouradian nail or some form of fixation from below into the head has also been described.

In complicated fractures, in patients with very osteoporotic bone, and in other circumstances, olecranon traction offers an alternative method of obtaining and maintaining reduction. Overhead olecranon pin traction is continued for 2 to 3 weeks or until the fracture is secure enough to be brought down to the side. A sling is used for comfort and support until there is clinical evidence that the fracture fragments are moving in unison. Assisted exercise can then be commenced.

Three-Part Fractures

Obtaining and maintaining a reduction with closed treatment is difficult in these injuries (Fig. 8). In the active patient they are usually best treated with open reduction and internal fixation or, in rare cases,



A

B

Fig. 7 Methods of open reduction and internal fixation of a two-part surgical-neck fracture. **A,** Combination of intramedullary-rod fixation and tension-band technique. **B,** Use of an intramedullary rod with a proximal interlocking screw.

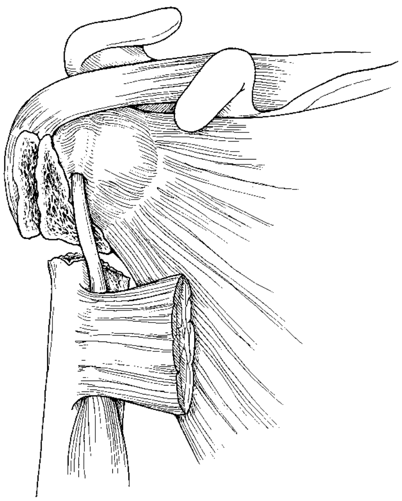


Fig. 8 Three-part displaced greater-tuberosity fracture.

with prosthetic hemiarthroplasty. Simply accepting a deformity may result in malunion and stiffness of the shoulder.[20-22] However, accepting the deformity of the displaced three-part proximal humeral fracture may be an option for selected patients who are medically unfit or unable to participate in the intense rehabilitation program required.

Closed reduction and percutaneous pinning has been proposed as an alternative means of achieving acceptable results with minimal disruption of the surrounding blood supply and soft tissues, provided an acceptable reduction can be obtained. Although the head-shaft segment can be reduced, the challenge is to reduce the tuberosity segment as well. Jaberg et al[3] reported the results with this method for unstable two- and three-part fractures.

Open reduction and internal fixation with a buttress T plate was once popular, but several studies have reported inferior results and high failure rates.[18,23,24] This technique involves extensive soft-tissue dissection, which may disrupt the remaining blood supply to the humeral head, leading to necrosis. The cancellous bone of the humeral head is often inadequate to provide adequate screw purchase and fracture fixation. There is a tendency to place the hardware too proximally, which may result in secondary impingement, necessitating a second surgical procedure to remove the hardware. For these reasons, this technique has fallen out of favor for the treatment of most displaced three-part proximal humeral fractures unless the patient has excellent bone stock and large fracture fragments.

Figure-of-eight tension-band wiring was popularized by Hawkins et al,[2] who reported satisfactory results in a series of 14 patients with three-part proximal humeral fractures. The advantages of this method include adequate visualization of the fracture fragments, which should ensure anatomic reduction with minimal soft-tissue stripping; preservation of the vascular supply to the humeral head; and secure fixation of the fracture fragments relying on soft tissue rather than bone. Complications with this treatment have been reported to be minimal. Avascular necrosis of the humeral head did develop in two of their patients, only one of whom was symptomatic enough to require revision to hemiarthroplasty. We believe that tension-band wiring is an excellent method of treatment for three-part proximal humeral fractures because it provides fragment fixation that is secure enough to allow early passive range-of-motion exercises.

In this technique, 18-gauge wire or No. 5 nonabsorbable suture is passed through or under the rotator cuff as well as through the tuberosity. A colpotomy needle is helpful in the passage of the wire or suture. A drill hole is made in the shaft of the humerus approximately 1 cm below the fracture site. The wire or suture is then passed through the hole and looped back in a figure-of-eight fashion (Fig. 9).

Tanner and Cofield[25] have suggested that rapid restoration of

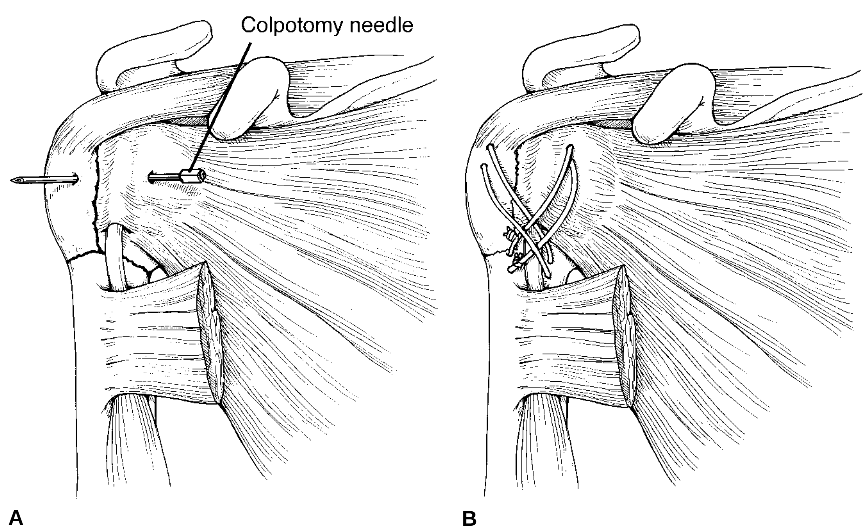


Fig. 9 Repair of a three-part displaced greater-tuberosity fracture. **A,** Reduction of a three-part fracture with preparation for tension-band technique. A colpotomy needle is helpful in passage of the wire or suture. **B,** Figure-of-eight tension-band wiring technique.

shoulder function may be more predictable in some older patients if immediate hemiarthroplasty is performed. For this goal to be achieved, adequate fixation of the tuberosity to the shaft is required. In most cases, the quality of the rotator cuff tissue is more than adequate to ensure blood supply and a means of fixing the tuberosity.

Four-Part Fractures

Immediate hemiarthroplasty has become the accepted method of treatment for displaced four-part humeral fractures (Fig. 10). Such fractures, with or without associated dislocation, have been reported to be followed by avascular necrosis with an incidence as high as 90%.[20] The number of affected patients who later become symptomatically disabled is unknown, but most surgeons agree that unless the patient is very young and active, immediate arthroplasty is the treatment of choice.

Jakob et al[26] have stressed the need to review the radiographs carefully before proceeding with hemiarthroplasty, to ensure that the fracture has not been mistaken for a four-part valgus impacted pattern. In the four-part valgus impacted fracture, the rate of avascular necrosis is significantly lower (20%) than in the classically described four-part fracture, where it may approach 90%.[20] Closed reduction or limited open reduction and minimal internal fixation can produce satisfactory results.[26]

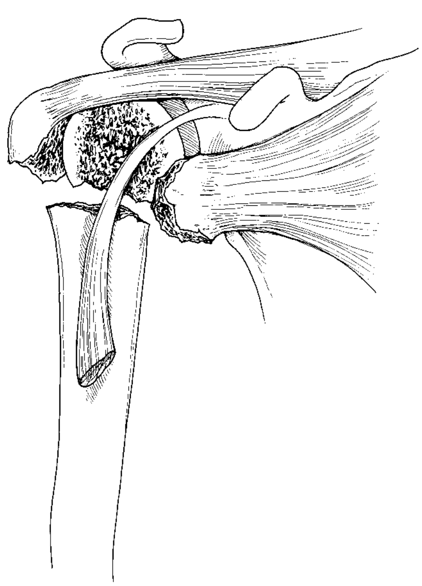


Fig. 10 Displaced four-part proximal humeral fracture.

Immediate prosthetic replacement for proximal four-part humeral fractures has met with varied success. In Neer's series,[20] overall good and excellent results were consistently obtained. Other authors have reported satisfactory but less optimal results.[25] Their poor results have been attributed to technique errors, such as failure to appropriately reconstruct the rotator cuff, failure to obtain bony union of the tuberosities to the shaft, or failure to achieve anatomic humeral offset, which provides a normal lever arm for the deltoid and supraspinatus.[25] Many failures are directly related to poor selection criteria, such as accepting alcoholic and demented patients who are unable to cooperate in the rehabilitation programs.[27]

Strict adherence to surgical detail will avoid the common pitfalls and ensure more reproducible results. Most failures of immediate hemiarthroplasty for four-part fractures are the result of inability to restore normal humeral length and appropriate retroversion (Fig. 11, A and B). If the prosthesis is placed too distally, there will be a risk of inferior subluxation, and tension will not be restored to the musculotendinous aspect of the rotator cuff. If proper humeral retroversion is not achieved, instability of the shoulder may result. Both humeral length and retroversion can be difficult to assess intraoperatively since bone is always missing from the proximal humerus.

Proper humeral height can be assessed at the time of prosthesis placement. If the tuberosities can be easily brought down to the shaft when the arm is held in a slightly abducted position and only one finger can be placed between the head and acromion, one can be confident that humeral length has been restored. With this technique, usually at least one hole in the flange of the prosthesis can be visualized. Appropriate head size is assessed by the ability to close the subscapular tendon and obtain normal external rotation.

Proper retroversion of the humeral component is also critical to the success of the surgical procedure. The goal is to recreate the normal 35 to 40 degrees of humeral retroversion. This can be accomplished by putting the flange of the prosthesis with the holes just posterior to the bicipital groove or by externally rotating the limb 35 to 40 degrees and placing the flange parallel to the floor. Once humeral length has been restored and retroversion recreated, visual landmarks will aid the surgeon in cementing the prosthesis into its proper position. This is then followed by bone grafting and securing the tuberosities to the shaft (Fig. 11, C).

Success in treating these injuries is related to an accurate diagnosis, realistic patient expectations, the skill of the surgeon, and exclusion of patients who are unable to cooperate with the rehabilitation program.

Fracture-Dislocations

Fracture-dislocations require reduction of the humeral head and are usually managed according to the fracture pattern. Left untreated, a dislocation condemns the patient to a poor functional result. Management can often be complicated by associated neurologic compromise, such as axillary or brachial nerve injury. Unrecognized disruption of the axillary artery can prove cata-

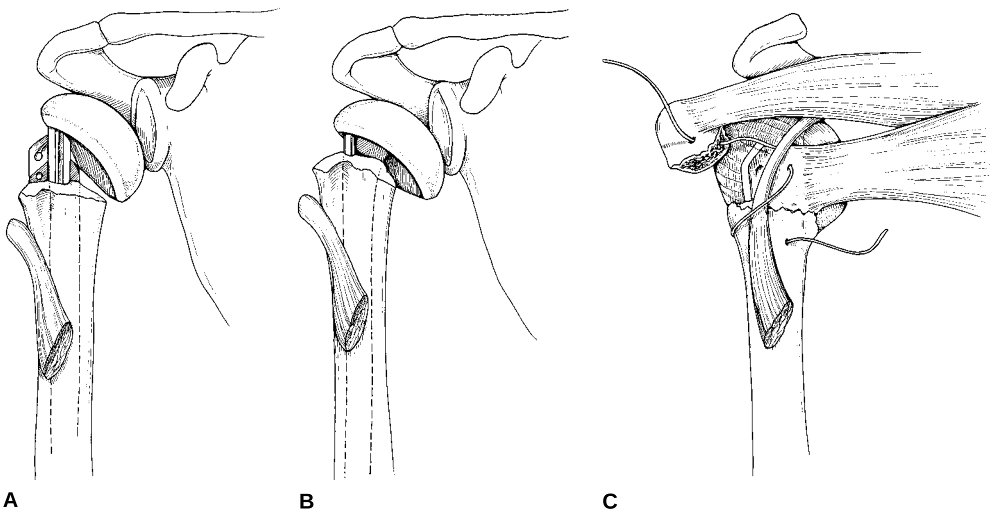


Fig. 11 Repair of a four-part displaced proximal humeral fracture. **A** and **B,** Technique of cementing humeral prosthesis to restore humeral length and achieve proper retroversion. **C,** Figure-of-eight tension-band wiring to reapproximate fractured tuberosities.

strophic. Angiography should be performed without delay in suspected cases, since early diagnosis and repair are crucial to outcome.

Articular-Surface Fractures

Impression defects or head-splitting fractures may result when the humeral head has been severely impacted against the glenoid rim. Impression fractures most often occur with posterior dislocation. McLaughlin[28] was the first to describe a locked posterior dislocation with an impression fracture in the area of the lesser tuberosity.

Management is determined by the size of the impression defect and the time the locked posterior dislocation has been present. In the case of an acute injury with less than a 20% impression fracture, the joint will usually be stable following closed reduction.[29] Immobilization for 6 weeks in external rotation will restore long-term stability. When a 20% to 45% defect has been present for less than 6 months, the McLaughlin procedure or Neer's modification of the McLaughlin transfer can be used. These techniques fix the lesser tuberosity and its attached subscapularis tendon with a screw into the head defect. Spica immobilization in external rotation is employed postoperatively. When there is a greater than 45% impression defect or dislocation has been present for more than 6 months, hemiarthroplasty is recommended. If the glenoid is involved, total shoulder arthroplasty may be considered.

The longer the dislocation has been present, the less retroversion of the prosthesis should be employed. For example, in a long-standing locked posterior dislocation, the humeral component should be put in approximately neutral version rather than the usual 35 to 45 degrees of retroversion. This positioning will immediately restore stability and allow early range-of-motion exercises.

The rare head-splitting fracture may occasionally be reduced closed if it consists of two large fragments. Open reduction and screw fixation are usually required if there are two or three large segments. Comminution with multiple segments usually requires hemiarthroplasty.

Positioning for Surgery

Most patients are positioned in a semisitting "beach chair" position, with the head rotated to the side opposite the affected shoulder. Either regional or general anesthesia can be used, depending on the surgeon's preference. To prevent the patient from sliding down the operating table, a pillow is placed behind the knees and a seat belt is placed across the patient's thighs. The bladder of a blood pressure cuff may be positioned under the ipsilateral scapula and inflated to bring the shoulder into the most advantageous position for surgical approach. In complex fracture patterns, especially in the presence of a posterior dislocation that may entail the need for an additional posterior approach, the patient should be placed in the lateral decubitus position. A sterile stockinette permits free manipulation. Intravenous antibiotics are administered 30 minutes prior to surgical incision, and two doses are given postoperatively.

Surgical Approach

Two utilitarian approaches are used for the majority of proximal humeral fractures. The limited deltoid-splitting approach is useful for isolated greater-tuberosity fractures and two-part surgical-neck fractures treated with intramedullary nailing (Fig. 12). A superolateral incision is made beginning at the anterolateral aspect of the acromion and coursing distally for 4 to 5 cm. The deltoid fibers are split bluntly, and the fracture is identified. One must remember during the deltoid split that the axillary nerve courses laterally, lying approximately 3 to 5 cm distal to the lateral margin of the acromion.

The more extended deltopectoral incision measures 12 to 15 cm in length and originates at the anterolateral corner of the acromion, curving toward the coracoid and ending at the deltoid insertion (Fig. 13). The cephalic vein can be taken medially or laterally. If the vein is taken laterally, excessive tension often results, leading to venous disruption. The insertion of the pectoralis major is partially released for exposure. Adducting the humerus during the procedure aids in relaxing the deltoid. If excessive deltoid tension is present, a transverse division of the anterior 1 cm of the deltoid insertion can be used to reduce muscle trauma. Blunt dissection is then carried out in the subacromial space to free any adhesions. A deltoid retractor is placed deep to the deltoid and acromion and superficial to the rotator cuff and humeral head. The coracoacromial ligament may be released superiorly for improved exposure.

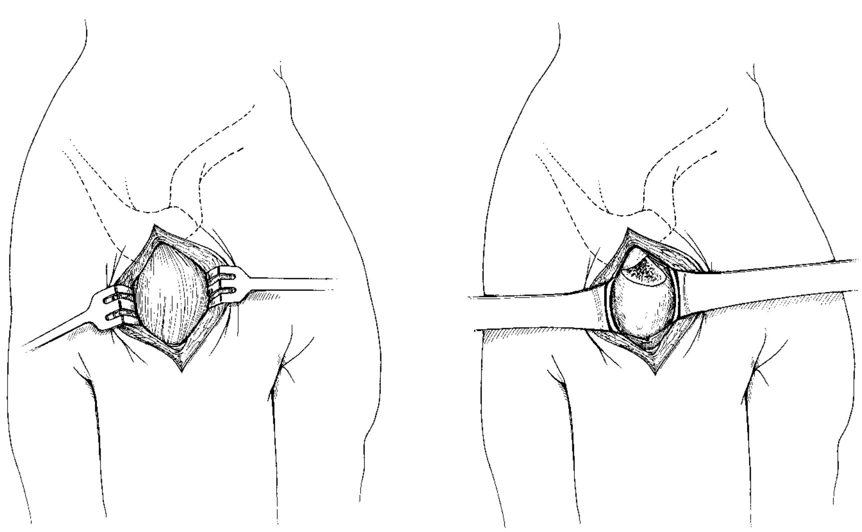


Fig. 12 Limited deltoid-splitting approach.

Rehabilitation

The rehabilitation program must be individualized to optimize the recovery of shoulder function. The surgeon and the physical therapist must convey to the patient a clear understanding of what is expected to achieve short- and long-term goals. The postoperative management program has three well-defined phases: phase I consists of passive or assisted range-of-motion exercises; phase II consists of active range-of-motion exercises with terminal stretching; phase III is a resisted program with ongoing active motion and terminal stretching.

Phase I begins on day 1, often with the aid of an interscalene block for early pain control, and continues for 6 weeks. It is essential to confirm that the fracture fragments move in unison and the fracture is stable. In rare instances, this phase may have to be delayed for up to 4 weeks if fixation is not rigid. This phase consists of passive forward elevation and external rotation of the involved shoulder assisted by the contralateral extremity. Assisted exercises begin in the supine position, with early emphasis on elevation and external rotation. Internal rotation exercises are included if the rotator cuff is intact (i.e., in surgical-neck fractures) or if secure fixation has been achieved by internal fixation (i.e., in tuberosity fractures). This exercise is frequently avoided in the early period after hemiarthroplasty with tuberosity repair for four-part fractures to avoid tension on the greater tuberosity segment. Pendulum exercises are used as a warm-up after a few days. Several days later, those exercises are performed sitting or standing. Toward the end of this initial 6-week phase, isometric strengthening exercises may be added. These are performed by applying gentle resistance to inward

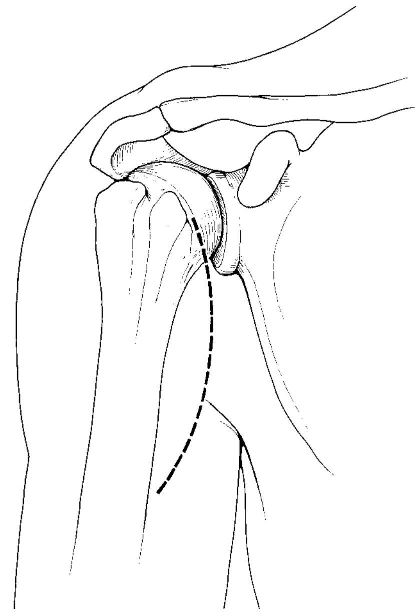


Fig. 13 Extended deltopectoral approach.

and outward rotation when the arm is at the side and the elbow is flexed to 90 degrees. Similar exercises are performed for flexion and extension. These activities need to be monitored carefully by the physician and the physical therapist. The exercises are taught to the patient and the patient's spouse so that they can be carried out at home.

Phase II usually begins at 6 weeks and consists of active range-of-motion exercises with terminal stretching. This phase is not begun until early union has been confirmed clinically and radiographically. The ability to resume the supine position allows the patient to concentrate on forward elevation and outward rotation. A full active range of motion in all planes is sought during this phase.

Phase III focuses on resisted strengthening and begins 10 weeks after surgery when union has been confirmed and adequate range of motion has been obtained. The challenge to achieve normal shoulder function is met with greater resistance during the strengthening exercises and the ongoing terminal stretching program. Maximal recovery is rarely achieved before the end of the first postoperative year.

Complications

Many complications, both specific and nonspecific, are reported to follow closed and open treatment of displaced proximal humeral fractures. Infection, neurovascular injury, malunion, nonunion, hardware failure, joint stiffness, and heterotopic ossification can result after the treatment of any fracture. Avascular necrosis, on the other hand, is a specific complication of significantly displaced proximal humeral fractures.[20]

Infection occurs infrequently after open reduction and internal fixation of displaced proximal humeral fractures. Fortunately, the proximal humerus has adequate soft-tissue coverage with good vascular supply to the tissues, decreasing that risk.

Neurovascular injuries have been well documented following displaced proximal humeral fractures. Stableforth[30] reported a 5% incidence of axillary artery compromise and a 6.2% incidence of brachial plexus injuries. Vascular injuries most often are associated with penetrating or violent blunt trauma caused by the initial injury, but can also occur after open reduction and internal fixation.[31] If a vascular injury occurs, the lesion is usually found at the junction of the anterior humeral circumflex and axillary arteries. The diagnosis may be difficult to make, since peripheral pulses are often normal as a result of collateral circulation. An expanding hematoma, pallor, and paresthesias are all suggestive of a vascular injury. Paresthesias in the corresponding neurologic distribution are often the most reliable clinical sign. Since early diagnosis and repair are crucial to the outcome, angiography should be performed without delay when a vascular injury is suspected.

The axillary nerve is the most susceptible to injury following fractures with and without dislocation of the proximal humerus. The axillary nerve provides motor supply to the deltoid and teres major, with sensory distribution over the lateral aspect of the upper arm. A normal sensory examination of the skin overlying the lateral deltoid is not always indicative of an intact axillary nerve. A more reliable means of testing the integrity of the axillary nerve is by palpating all three slips of the deltoid muscle for active contraction. However, this too is sometimes difficult to accurately assess in an acute fracture when there is associated pain. Therefore, an electromyogram should be obtained if a nerve injury is suspected. This study should be obtained no earlier than 4 weeks after the injury; the results are most accurate then and can be used as a baseline for further comparisons of recovery of function. The majority of these injuries are secondary to neuropraxia and will improve with time. If a complete axillary nerve injury does not improve within a 3- to 6-month period, surgical exploration is warranted.

Malunion of the proximal humerus can cause significant functional limitations. When the greater tuberosity heals in a superior or medial position, the space beneath the subacromial arch is limited, and impingement occurs when the arm is abducted or externally rotated. This problem can be corrected with a salvage surgical procedure involving an osteotomy of the greater tuberosity and mobilization of the rotator cuff. This procedure is often difficult because the anatomy is distorted and there is often extensive searing.

Nonunion at the surgical neck is not uncommon, particularly in the case of two-part displaced shaft fractures and three-part fractures. Interposition of soft tissue, excessive soft-tissue dissection, inadequate immobilization, poor patient compliance, and overaggressive physical therapy all contribute to nonunion. Treatment in these cases includes open reduction and internal fixation, autogenous bone grafting, and spica-cast immobilization. The use of Rush nails with tension-band wiring is the preferred method of internal fixation in these difficult cases.

Joint stiffness can occur as a result of either closed or open treatment. Prolonged immobilization with either means of management can result in bursal or capsular adhesions. Prominent hardware (e.g., rods, plates, screws, and wires) can limit mobility. Persistence with daily terminal stretching programs is the best management, but may require up to 18 months for full benefit. Forced manipulation carries the risk of refracture and is rarely required.

Heterotopic ossification appears to be related to both repetitive forceful attempts at closed reduction and delay in open reduction beyond 1 week of the initial injury. Inadequate irrigation to wash out bone fragments following open reduction and internal fixation may also increase the risk. Exercises to maintain range of motion should be the mainstay of treatment. After 1 year, if a bone scan shows no activity, excision of the heterotopic bone with soft-tissue releases may be considered.

Avascular necrosis is one of the most severe complications following displaced three-part proximal humeral fractures and some two-part fractures. It results from disruption of the vascular supply to the humeral head.[20] The incidence of avascular necrosis ranges from 3% to 25% in three-part fractures and is as high as 90% in four-part fractures.[20,32] The incidence of avascular necrosis has been noted to be slightly higher in patients who undergo open reduction and internal fixation than in those who undergo closed treatment. Factors that may be responsible for disruption of the blood supply include the initial trauma of the injury and the extensive soft-tissue dissection required in open reduction and internal fixation. It is uncertain how many patients with avascular necrosis will become symptomatic enough to warrant further surgery. If resorption or collapse of the articular segment occurs, pain and loss of motion may result. In these cases, hemiarthroplasty can provide significant functional improvement. Total shoulder arthroplasty may be necessary if joint incongruity involves the glenoid surface.

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