Surgical Treatment of Fractures of the Proximal Humerus

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INTRODUCTION

Despite recent advances in imaging and fixation techniques, the treatment of displaced fractures affecting the proximal humerus remains a challenge. Many such fractures occur in elderly patients who may have poor general health, poor bone quality, and poor postoperative compliance. The remainder tend to occur in younger patients with better bone quality who have experienced high-energy trauma that can cause associated severe soft-tissue injuries. Specifically, the labrum, capsule, rotator cuff, brachial plexus, peripheral nerves, and blood vessels can all be injured in cases of high-energy trauma. As with the treatment of almost any fracture, the goal remains to obtain and maintain an acceptable reduction while healing progresses. Although this goal often can be achieved with limited internal fixation and a period of prolonged immobilization, the subsequent stiffness can be disabling. Optimal treatment involves providing fixation that will withstand the stress of early passive movement, an ideal that cannot always be attained.

In situations in which the humeral head is not reconstructable, replacement arthroplasty may be indicated. However, unlike hemiarthroplasty of the hip for femoral neck fractures, successful humeral head replacement after trauma still requires bone-to-bone healing. The tuberosities must unite to the shaft if any degree of function is to be restored.

This manual will discuss surgical treatment of fractures of the proximal humerus, focusing on indications, approaches, specific techniques, and outcomes. The manual will conclude with a specific, detailed review of humeral head replacement in cases of acute fracture of the proximal humerus.

SURGICAL INDICATIONS

DISPLACED FRACTURES

Most fractures of the proximal humerus (approximately 80%) are minimally displaced, impacted, relatively stable, and able to be treated conservatively. Fractures with displaced, unstable patterns are typically reduced, with either a closed or open method, and then stabilized or fixed with various types of implants. Although Neer’s classification system of fractures of the proximal humerus is well known, the central importance of displacement has probably not been emphasized enough.

Determining whether or not a patient’s fractured bone segments are displaced to a significant degree requires high-quality radiographs, and these images can be difficult to obtain in acutely injured patients. Often, it is helpful for the operating surgeon to assist the radiology technician in supporting the arm, positioning the patient, and confirming appropriate trajectory of the beam. In most cases, high-quality radiographs will allow the fracture pattern to be understood. When they do not, thin-cut computed tomography (CT) scanning can be done. This modality allows the option of 3-dimensional reformatting, which can be particularly helpful in the evaluation of complex fractures and malunions.

NEER’S CLASSIFICATION SYSTEM

If the necessary high-quality radiographs are obtained, Neer’s classification system is a practical and useful guide to treatment, particularly when applied to fractures of the surgical neck. Fractures with less than 1 cm of displacement or 45 degrees of angulation of the head fragment (relative to the shaft) can generally be treated by a closed method. However, these traditional guidelines may not apply to the greater tuberosity. Others have suggested that less than 1 cm of displacement of the greater tuberosity (approximately 5–10 mm) may be significant in some patients. This small degree of displacement can be difficult to determine, given the variability in individual anatomy. Therefore, comparison views of the opposite shoulder with the arm held in a similar degree of external rotation can be useful.

The most common fracture patterns that require surgical treatment are 2-part fractures (with shaft displacement), 3-part fractures (with shaft and tuberosity displacement), and 4-part fracture-dislocations (typically occurring in elderly patients). Less common patterns include the isolated 2-part greater tuberosity fracture, the 2-part anatomic neck fracture (with displacement of the head segment only), and the so-called valgus-impacted pattern.
This valgus-impacted “four-part” pattern\(^8-10\) (Figure 1) seen in some fractures of the proximal humerus deserves particular attention. Subtle impaction of the lateral aspect of the head can often mimic greater tuberosity displacement. If this fracture pattern is not appreciated prior to surgery, the greater tuberosity may be irreducible. Although all 4 segments are fractured, the displacements typical of this pattern are generally not enough to qualify as true 4-part fractures, according to Neer’s criteria. The rate of avascular necrosis after this type of fracture is low.

**ANATOMIC CONSIDERATIONS**

The blood supply to the humeral head has been well described\(^11,12\) and should be respected during internal fixation. During surgery, this means avoiding soft-tissue disruption in the region of the arcuate artery that runs near the lateral aspect of the bicipital groove. Equally important is an awareness of the course of the axillary nerve and its vulnerability during exposure and fixation of fractures that involve displacement of the greater tuberosity. Protection of the axillary nerve is most easily accomplished by abducting the arm slightly to relax the deltoid muscle. These maneuvers become particularly useful in cases that are treated late and in cases of revision surgery in which extensive callus or scar tissue obscures the anatomical planes.

The points available for fixation in the proximal humerus include the shaft, head fragment, and tuberosities. The shaft is characterized by its hollow tubular structure and constant availability as a point of fixation for plates and screws, intramedullary devices, and prosthetic stems (in combination with bone cement). The tuberosities are characterized by their fragility, fragmentation, and consistency of rotator cuff tendon attachment. These tendon attachments serve as a second point of consistent and reliable fixation. The quality of the humeral head fragment varies with the age of the patient and the pattern of the fracture. In elderly patients, the head fragment is most often a thin, hollow shell of bone that precludes rigid fixation but can be supported by a bone graft or a fixed-angle device such as a blade plate.\(^13\) In contrast, younger patients often have ample high-quality cancellous bone available in the humeral head that allows adequate purchase and fixation with standard bone screws.

**OTHER AGE-RELATED CONSIDERATIONS**

In addition to bone quality, other patient characteristics associated with age influence decision making in the management of fractures of the proximal humerus. For example, younger patients tend to experience high-energy trauma that often results in associated dislocations and soft-tissue trauma. In this population, there is a high propensity of postoperative stiffness, so the goal of achieving stable fixation becomes paramount. Fortunately, stable fixation can be achieved consistently when there is adequate bone quality and good postoperative compliance with passive exercises. In contrast, older patients are more often subject to low-energy trauma (eg, falls), typically have poorer bone quality, and often have limitations of both cognitive capacity and the social support necessary to protect the fixation by avoiding active use of the arm during the early postoperative period.

A patient’s ability to comply with postoperative instructions becomes critical when fractures of the proximal humerus are treated with replacement arthroplasty, because this surgical procedure also mandates protection and rehabilitation postoperatively to allow the opportunity for healing between the greater tuberosity and shaft. Thus, it is not surprising that results of hemiarthroplasty in elderly patients have been only fair at best.
INTRAOPERATIVE SETUP AND POSITIONING

Regardless of the planned procedure (eg, closed reduction with percutaneous fixation, open reduction with internal fixation, hemiarthroplasty), the intraoperative setup and positioning used in repair of fractures of the proximal humerus remain consistent. Key features include neutral positioning of the cervical spine and lateral positioning of the shoulder to allow access to the intramedullary canal of the humerus and neutral positioning of the cervical spine. (Reprinted with permission from Moehring H, Greenspan A, editors. Fractures: diagnosis and treatment. New York: McGraw-Hill/Appleton & Lange; 2000:220.)

SURGICAL PROCEDURES

INTRAOPERATIVE SETUP AND POSITIONING

Regardless of the planned procedure (eg, closed reduction with percutaneous fixation, open reduction with internal fixation, hemiarthroplasty), the intraoperative setup and positioning used in repair of fractures of the proximal humerus remain consistent. Key features include neutral positioning of the cervical spine and lateral positioning of the shoulder to allow access to the intramedullary canal (Figure 2). Prior to preparing and draping the patient, the surgical team should confirm that fluoroscopic images of the entire humeral head can be obtained, in order to ensure that similar images will be available as needed during the process of internal fixation.

Figure 2. A view from behind the operating table demonstrating the important features of patient positioning: lateral positioning of the shoulder to allow access to the intramedullary canal of the humerus and neutral positioning of the cervical spine. (Reprinted with permission from Moehring H, Greenspan A, editors. Fractures: diagnosis and treatment. New York: McGraw-Hill/Appleton & Lange; 2000:220.)

Particular attention should be directed to cleansing of the skin. Many fractures are treated surgically several days after the injury, and most patients find maintenance of axillary hygiene impossible during this interval. Subsequent bacterial growth in the region of the fracture can become substantial and theoretically contribute to deep infection postoperatively.

SURGICAL APPROACHES

Percutaneous Approach

In certain cases, a percutaneous approach is valuable. Terminally threaded wires (eg, 2.5 mm Schanz pins) are typically used. Although other devices (eg, cannulated screws, nails) can be applied in a percutaneous fashion, the following guidelines recently set forth by Gerber still apply: good bone quality, the ability to obtain a satisfactory closed reduction, satisfactory stability during fluoroscopic examination, and good patient compliance with the necessary period of postoperative immobilization should be present.

A percutaneous approach is well suited for fractures with minimal comminution. In younger patients, this type of fracture typically means a 2-part surgical neck fracture. The application of this technique to 3- and 4-part fractures is more challenging and may not be possible in all cases.

In patients with poor bone quality, percutaneous or minimally invasive fixation can still be possible with use of an intramedullary device. As with any nailing procedure, satisfactory closed reduction should ideally be obtained prior to nail insertion. Equally essential is the establishment of an appropriate starting point for the device. If a straight implant is placed through the greater tuberosity, the nail will invariably push the head segment into varus alignment as it enters the intramedullary canal of the humerus.

A unique and relatively simple intramedullary device was developed by Evans approximately 2 decades ago when he devised a long prestressed stainless steel staple that could be implanted through a small incision and deltoid split. This implant provides rotational stability by gaining purchase in the subchondral bone of the humeral head and endosteal surface of the humeral shaft.

Anterosuperior Approach

Depending on the pattern and complexity of the fracture, a deltoid-splitting incision or even a formal anterosuperior approach with removal of a portion of the deltoid origin from the acromion can be applied. If this approach is selected for the treatment of fractures of the greater tuberosity, care should be taken, as always, to avoid excessive distal propagation of the split.
and subsequent injury to the axillary nerve from overzealous retraction.

**Long Deltopectoral Approach**

Almost all fractures of the proximal humerus can be addressed through a long deltopectoral approach (Figure 3), particularly if the approach is modified by the following 6 steps: (1) the incision is placed slightly lateral to the deltopectoral interval, extending from the clavicle to the deltoid origin; (2) the deltopectoral interval is developed in its entirety from the clavicle through the deltoid origin; (3) the plane between the deltoid and the coracoacromial ligament is developed; (4) a subbursal exposure is performed with complete release of adhesions that can limit mobility of the rotator cuff, humeral shaft, and fracture fragments of the proximal humerus; (5) a deltoid retractor is used to effectively displace the deltoid muscle mass posteriorly and lever the proximal humerus forward; (6) retention sutures are placed in the supraspinatus, infraspinatus, and subscapularis muscles, allowing the tuberosity fracture fragments to be controlled and reduced.

**Implants**

A variety of implants are available for use in surgical treatment of fractures of the proximal humerus, including sutures, flexible wires, rigid pins, screws, intramedullary nails, and plates. In actuality, combinations of these devices are often used to achieve stable fixation.

**Sutures**

Sutures have the desirable qualities of radiolucency, simplicity of use, and softness of texture. Heavy suture material is perhaps the material of choice for fixation of the tuberosities (with or without a prosthesis), particularly when the tuberosities are comminuted and the suture is placed at the bone-tendon junction. However, suture fixation alone typically does not provide adequate rigidity to control larger segments of bone, such as the head relative to the shaft in surgical neck fractures. In these situations, tension-band wiring as described by Hawkins and colleagues, with or without additional intramedullary fixation, has proved effective. The latter method is particularly attractive in elderly patients with poor bone quality in whom the only available points of fixation are the shaft and the rotator cuff.

**Intramedullary Nails**

Although intramedullary nails can be effective in repair of fractures of the proximal humerus, they can necessitate violation of the rotator cuff. At times, the nails can become very prominent and cause subacromial impingement and wear of the supraspinatus tendon (Figure 4).

**Plates**

Plate fixation has a definite role in the treatment of fractures of the proximal humerus. Indications for use of plates include fixation of fractures extending distally into the diaphysis, severe metaphyseal comminution, and support of a fragile head segment, particularly after elevation from a valgus-impacted position. Some authors have suggested that plate fixation of the proximal humerus can cause avascular necrosis. This potential complication may be related more to injury to the arcuate artery (supplying blood to the humeral head) than to the implants. Esser recently reported a very low incidence of avascular necrosis with plate fixation. Of course, posttraumatic avascular necrosis of the humeral head can and does occur in the absence of surgical treatment. If plates are used, they should be positioned appropriately low on the tuberosity to avoid iatrogenic subacromial impingement. Plates can also serve as an important point of attachment for multiple tension band sutures. This additional fixation can neutralize the pull of the rotator cuff and prevent late hardware failure and varus deformity.

**Results of Internal Fixation**

Analysis of the available literature on internal fixation of fractures of the proximal humerus is somewhat limited...
by variations in the fracture patterns reported, the implants used, the follow-up period established, and the grading scales applied. Despite these variations, however, satisfactory results are achieved in approximately 80% of cases. Poor prognostic factors include advanced age, poor bone quality, and more severe fracture patterns (ie, 3- and 4-part fractures)—particularly when associated with a dislocation of the humeral head fragment.

Regardless of the severity of the injury or the type of fixation device selected, anatomic reduction is crucial. Gerber’s work suggests that if the tuberosities and head segment can be maintained in an anatomic or near-anatomic position through fracture healing, the clinical results are consistently satisfactory, even in the presence of posttraumatic avascular necrosis.

HUMERAL HEAD REPLACEMENT IN ACUTE FRACTURES

GENERAL CONSIDERATIONS

In 1970, Neer published his classic articles on fractures of the proximal humerus. In part II of the series, the results of treatment of 4-part displacements were reported. With this severe pattern of injury, both nonoperative treatment and open reductions led to dismal results in every case; only humeral head replacement (HHR) produced a satisfactory outcome consistently. Although others have also published their experience, Neer’s work remains influential and has directed treatment for the past 30 years.

During the past 2 decades, most 4-part fractures requiring HHR have been treated with implants originally designed to treat glenohumeral arthritis. The results have been variable. More recently, implants specifically designed to treat fractures of the proximal humerus have been developed in hope of improving clinical results.

INDICATIONS FOR HUMERAL HEAD REPLACEMENT

Recently, the indications for HHR in the setting of acute trauma have become more refined. In general, the use of HHR is reserved for elderly patients with poor bone quality and fracture patterns that preclude salvage of the humeral head or stable internal fixation (eg, head-splitting fractures, Neer 4-part fractures, selected Neer 3-part fractures, fracture-dislocations in patients with poor bone quality and a very small head fragment, selected severe impression fractures that involve more than 40% of the articular surface, selected anatomic neck fractures in which internal fixation is not possible).

Typically, in patients younger than 60 years, an attempt is made to salvage the proximal humerus rather than to replace it. Moreover, the advent of improved implants for internal fixation, a new understanding of
the clinical significance of posttraumatic avascular necrosis, and the relatively high rate of complications reported in HHR in cases of acute trauma have resulted in a trend away from HHR toward internal fixation in these patients. Additionally, a group from Paris has recently developed a new implant, the Bilboquet device, which may further limit the indications for HHR for acute fractures, even in the setting of poor bone quality.

**SURGICAL TECHNIQUE**

**Preliminary Considerations**

If HHR is attempted, the objective should be to reconstruct the proximal humerus anatomically. The importance of prosthetic head size, implant position, and tuberosity position have been emphasized by several authors. These studies suggest that HHR has little chance of restoring satisfactory function of the shoulder unless the height of the humeral head, the degree of retroversion, the humeral head size, and the tuberosity position are anatomic or near-anatomic (ie, within a few millimeters or degrees). Achieving this goal consistently requires good planning, instrumentation, and surgical technique.

**Preoperative Planning**

Careful preoperative planning is essential before HHR. A high-quality radiograph of the opposite shoulder is useful. The single best view is an anteroposterior view of the scapular plane with the arm held in external rotation. Because the goal of surgery is to recreate normal anatomy, templating the opposite uninjured proximal humerus helps determine appropriate stem size, head size, head offset, and tuberosity position. Preoperative templating complements intraoperative guidelines such as soft-tissue tension. A full-length view of the humerus with radiographic markers also can be useful to assist in determining true arm length.

**Patient Positioning**

The beach-chair position is recommended for HHR. Several details are worth emphasizing. The legs and feet should be elevated, with hip flexion limited to 90 degrees (or less) and the table placed in a slight Trendelenburg position. These steps minimize lower extremity venous stasis and lessen the tendency of larger patients to slide down the table during the procedure. The cervical spine is positioned neutrally to minimize the chance of stretch injury to the cervical cord and brachial plexus. Lateral positioning of the shoulder allows surgical access to the humeral canal and improved fluoroscopic imaging.

**Skin Preparation**

Particular attention should be directed to cleansing of the skin before HHR. As previously stated, many fractures are repaired surgically several days after the initial injury, and most patients are unable to maintain axillary hygiene during the intervening period. Subsequent microbial growth in the region of the fracture can be substantial and can contribute to a postoperative deep infection. For this reason, after anesthesia is induced, prescrubbing the axilla with alcohol is recommended prior to proceeding with the standard surgical preparation.

**Surgical Approach and Exposure**

A modification of the deltopectoral approach is used in HHR. The entire deltopectoral interval from the clavicle to the humerus is developed. Specifically, all veins draining the deltoid (between the medial border of the muscle and the cephalic vein) are cauterized or ligated. Leaving the cephalic vein with the pectoralis major muscle allows better mobility of the deltoid and greater ease in exposing the posterior aspect of the greater tuberosity and shaft. The clavipectoral fascia is incised, and the subacromial/subdeltoid bursa is entered. Slight abduction of the arm at this point relaxes the deltoid muscle and protects the terminal branches of the axillary nerve. Periosteal attachments of the shaft and greater tuberosity are preserved to enhance healing after repair.

Deeper exposure of the dislocated humeral head fragment typically is achieved by working through a longitudinal fracture line in the greater tuberosity. This exposure is most often associated with a small longitudinal split supraspinatus tendon, which can be surgically enlarged towards the superior glenoid labrum, as needed, to gain access to the head fragment, glenoid, and upper portion of the humeral shaft. Although many texts illustrate 4-part fractures as occurring through the bicipital groove, most often the hard bone of the groove remains intact, with a coronal fracture line occurring just posterior to it.

Once exposed, the glenoid articular surface is assessed. Unless the patient suffers from an associated disease (eg, inflammatory arthritis), the glenoid cartilage is usually well preserved and does not merit replacement. Next, the shaft of the humerus is gently exposed, taking care to avoid iatrogenic stripping of the periosteum. At this point, drill holes and sutures should be placed in the upper portion of the shaft in anticipation of tuberosity repair after cementation.
Trial Reduction

The trial reduction process in cases of HHR can be divided into at least 3 steps: (1) restoration of humeral length, (2) restoration of appropriate humeral head retroversion, and (3) restoration of humeral head offset or size.

The length of the arm is determined by the height of the prosthesis. When the humeral head is positioned too low, permanent inferior subluxation can occur. If the implant is too high, the tuberosity and rotator cuff repair will come under excessive tension and may fail. Perhaps the most accurate method of restoring humeral length is to use a ruler. To this end, Boileau and Walch have developed an external fracture jig that has enabled surgeons more consistently to restore the length of the humerus during arthroplasty for fractures,34 and Williams and Rockwood have developed an internal jig that clamps to the diaphysis. Both jigs hold the trial implant in place during trial reduction and allow clinical assessment of height, retroversion, and tension of the rotator cuff with the tuberosities reduced. Similarly, Frankle has developed a modular system that allows the trial stem to be press fit for stability. The trial implant bodies are etched in 5-mm increments. Based on the preoperative plan, a surgeon can calculate how far above the shaft fragment to set the head. If these newer systems are not available, the trial implant is either held in place with a clamp or press fit with a sponge; the height and retroversion are then marked.

Several intraoperative guidelines can also be used to assess humeral height: (1) the tension in the long head of the biceps, (2) the tension of the reduced tuberosities, (3) the distance between the supraspinatus tendon and the coracoacromial ligament, and (4) the upper border of the anatomically reduced greater tuberosity. The latter is perhaps the most useful landmark. In most shoulders, the apex of the humeral head rests just above the greater tuberosity. This relationship and its variations can be appreciated on the radiograph of the opposite shoulder used for templating. During surgery, with the trial implant in place and the greater tuberosity reduced and provisionally fixed, a radiograph or fluoroscopic image of the shoulder can be obtained to confirm clinical impressions about the position of the implant and tuberosities.

Retroversion

In the setting of HHR to treat acute fractures of the humeral head, reliable landmarks are often absent, resulting in a tendency of the surgeon to malrotate the humeral component. It should be recognized that great variability exists in the degree of retroversion of the humerus,34,38–41 with the average value measuring 20 degrees relative to the epicondylar axis.34 If the forearm is used as a reference point, approximately 25 to 30 degrees of retroversion would be appropriate in most cases. Boileau and Walch have pointed out the negative consequences of excessive retroversion.34 If the greater tuberosity is reduced and repaired under a prosthetic head that is placed in too much retroversion, the repair will come under excessive tension when the arm is brought into internal rotation against the abdomen. Posterior tuberosity displacement cannot always be appreciated on radiographs and may be one cause of tuberosity resorption. Perhaps a more common cause of tuberosity migration is the failure of the shaft of the humerus to heal.

Cementation

Cement is used to gain immediate stability of the implant. However, the proximal metaphysis should not be filled with cement, because it is only the area available for tuberosity healing (Figure 5). Given the relatively high risk of infection, the use of antibiotics in the cement is reasonable.

Tuberosity Repair

Conditions for healing of the tuberosity to the shaft can be optimized by avoiding the tendency to excessively trim or thin the tuberosity or to fill the metaphysis with metal and cement and by selecting a humeral head size similar to that of the fractured head or of the humeral

Figure 5. A radiograph showing a well healed tuberosity following hemiarthroplasty. (Reprinted with permission from Moehring H, Greenspan A, editors. Fractures: diagnosis and treatment. New York: McGraw-Hill/Appleton & Lange; 2000:223.)
head of the opposite side. Adjunctive cancellous bone grafting from the resected humeral head is advisable, and secure repair of the tuberosities is essential. The heavy suture placed in the configuration described by Hawkins and colleagues\(^1\) typically provides satisfactory stability. Additional fixation in compression can be achieved by placing cerclage sutures or wires around the medial neck of the implant and the tuberosities.

**REHABILITATION AFTER HUMERAL HEAD REPLACEMENT**

Once true anatomic reconstruction has been achieved in HHR (ie, the length of the arm is appropriate, the humeral head size and retroversion are appropriate, the tuberosity position is correct, the osteosynthesis is secure), near full passive range of motion should be possible. In practice, rehabilitation must be individualized in each case because of variations in bone quality and patient understanding. After repair of the tuberosities is achieved, the arm is taken through passive range of motion while the osteosynthesis site is examined directly. The limit at which passive motion brings the repair under stress is recorded. Postoperatively, supine passive elevation and external rotation are prescribed, to a limit of 5 to 10 degrees less than the intraoperative measurements. Occasionally, the tuberosity is so comminuted that a secure repair cannot be achieved, in which case a rehabilitation program with more limited goals is prescribed.\(^3\),\(^4\)

**RESULTS OF HUMERAL HEAD REPLACEMENT**

**Assessing Outcome**

Many grading systems have been used to assess the outcome of shoulder arthroplasty as treatment of fractures of the proximal humerus. Although this variability precludes a highly accurate comparison of results, most studies do report at least some shoulder range of motion and comfort. In our review of published series, there was a wide range in the values reported for mean elevation range of motion (ranging from 58 to 131 degrees).\(^27\),\(^42\) The severity of pain experienced by patients after HHR was also variable; patients with no pain or mild pain ranged from 60% to 95%.

A review of the Mayo Clinic’s experience with HHR for acute fractures was recently updated. Including cases from 2 previously published series,\(^1\),\(^4\)\(^8\) 75 HHRs were performed at Mayo between 1970 and 1998. The average follow-up interval was 40 months. Of the 75 patients involved in these procedures, 66 (88%) reported mild or no pain. Range of motion on active elevation and external rotation averaged 101 and 38 degrees, respectively.

These data and those of others\(^2\),\(^5\),\(^4\),\(^4\) suggest that patients treated with HHR for acute fractures are usually free of severe pain. Their functional outcome seems to be less predictable. Many patients are left with a restricted range of motion, especially on active arm elevation. Newer implants and techniques\(^3\) may allow average results to improve to the relatively high standard set by Neer some 30 years ago. The factors affecting outcome have been extensively discussed in the literature and include fracture pattern, timing of surgery, patient’s age, position of the implant, and aftercare.\(^2\),\(^2\),\(^2\),\(^4\),\(^5\),\(^4\)

**Fracture Pattern**

Two reports suggested better functional outcome for 3-part fractures treated primarily with HHR than for 4-part fractures.\(^2\),\(^4\) These results are not entirely unexpected, given the larger fragments of tuberosity available for repair in the setting of 3-part fractures.

**Timing of Surgery**

There is some rationale for early treatment of fractures of the proximal humerus with HHR, prior to the development of an unwanted scar, contractures, and bone deformity. Tanner and Gofield compared the results of HHR in patients with acute and chronic fracture, including patients with malunion; the complication rate was higher for cases in which HHR was delayed.\(^2\) In a study by Bosch and colleagues, the length of time between injury and hemiarthroplasty was the best predictor of outcome in most cases; the outcome was inversely proportional to the interval between injury and hemiarthroplasty.\(^4\) The results were significantly better after early operation, despite the fact that the fracture pattern was more severe in patients undergoing early operation.\(^4\)

**Age**

Patients of advanced age (ie, older than 70 years) who undergo HHR also tend to have less satisfactory results.\(^2\) This finding possibly results from the fact that elderly patients may be less determined than are younger patients to pursue a rigorous rehabilitation program after HHR because of their limited functional needs. Wretenberg and Ekelund\(^2\) also noted inferior results in their series in which patients who were, on average, age 82 years obtained only approximately 55 degrees of elevation; they added that these patients usually had decreased elevation in the contralateral non-operated shoulder as well, indicating that this decreased range of motion was somewhat related to physiologic age changes. Finally, in older patients, tuberosity fragments are more comminuted and osteoporotic, making
fixation and union less predictable. Poor functional results of arthroplasty in elderly patients are typically offset by their high rate of satisfaction, because pain relief plays a much greater role than does the demand for physical performance. Of interest, the mean age of patients in Neer’s study was 55 years. This consideration may have contributed greatly to the high rate of satisfactory results.

**Prosthesis Malposition**

Perhaps the most common reason for failure in HHR is prosthetic malposition. Boileau and Walch found that differences between the original anatomy and the prosthetic design led to altered biomechanics. In their clinical series, the most significant factor associated with a poor functional outcome was malposition of the prosthesis, especially when the prosthesis was placed too proud or in excessive retroversion. They also found a clear correlation between prosthesis positioning and greater tuberosity migration, leading to nonunion, malunion and late bone resorption. A recent study by Frankle found a correlation between head-to-tuberosity distance and patient functional outcome and satisfaction. A distance of 13 mm or more was associated with poorer results.

**COMPLICATIONS OF HUMERAL HEAD REPLACEMENT**

Many authors have recognized the challenges of achieving good results with HHR for acute trauma. An analysis of a series of 30 failed prosthetic replacements for displaced fractures of the proximal humerus showed that the single greatest cause of failure was detachment of the greater tuberosity. Loosening of the humeral prosthesis occurred in 13 shoulders, two of which were also infected; nerve injury was diagnosed in 30%, and glenoid erosion and malposition of the humeral prosthesis occurred in 23%. Ectopic formation was present in 16% of these failures.

In a recent review by Muldoon and Cofield, complications of HHR were diverse. Wound healing problems, infection, nerve injury, periprosthetic humeral fracture, component malposition, instability, tuberosity healing problems, rotator cuff tearing, reflex sympathetic dystrophy, heterotopic ossification, periarticular fibrosis, component loosening, glenoid arthritis with instability, tuberosity malunion or nonunion, and heterotopic bone formation were the most frequent complications.

In the Mayo combined series of 75 cases occurring between 1970 and 1998, complications occurred in 25 patients (35%), most often involving healing of the tuberosity and rotator cuff. There were 6 cases of nonunion of one or both tuberosities, 13 cases of mild-to-moderate anterosuperior instability related to rotator cuff insufficiency, 4 cases of infection (1 superficial, 3 deep), 1 case of wound hematoma, and 1 case of reflex sympathetic dystrophy. Five reoperations were necessary (3 to treat infections, 1 for tuberosity repair, 1 for drainage of a hematoma).

**CONCLUSIONS**

Treatment of fractures of the proximal humerus can be challenging. Although there is a potential for frequent complications, many can be avoided with careful preoperative planning and meticulous surgical technique and aftercare. Optimal function of the shoulder after acute trauma requires anatomic or near-anatomic reconstruction. Newer techniques, instruments, implants may improve clinical results.

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