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Hemiarthroplasty for Complex Four-Part Fracture of the Proximal Humerus: Technical Considerations and Surgical Technique

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Historical Perspective

The four-part fracture complex described by Neer is a rare but severely disabling injury to the proximal humerus [18]. It is an injury which, while historically rare, has become increasingly more common as the population ages and remains physiologically active. This injury is specifically disabling when it involves the dominant arm.

The severity of this injury is due to the associated vascular compromise, which occurs secondary to interruption of the ascending branch of anterior humeral circumflex artery as it courses around the proximal humerus and enters at the tuberosities around the bicipital groove [16]. These endostial vessels are at risk in fractures which involve one or both tuberosities. Disruption of this major blood supply leaves the proximal humerus susceptible to avascular necrosis. Four-part fractures are particularly susceptible since they include disruption of both tuberosities and are associated with a high incidence of avascular necrosis, ranging from 34% to 85% [15,24,26,27].

In addition to vascular compromise, these fractures are often associated with significant comminution, which makes stable open reduction/internal fixation extremely difficult. Because of these factors many surgeons have opted for a "wait and see" approach to treatment in some patients. The other treatment options have included closed reduction, open reduction with or without fixation, and hemiarthroplasty [2,15,17–20,23,24,26].

Schai, in comparing the results of these treatments in a group of patients who had sustained four-part proximal humeral fractures, noted that hemiarthroplasty gave statistically significant better results than both open reduction/internal fixation or conservative care [23]. In other series conservative treatment had only a 5% successful outcome [26]. Some authors have noted that four-part fractures treated acutely by hemiarthroplasty had significantly better results than those chronic four-part malunions treated later by arthroplasty [5,10,21]. With all these factors considered, hemiarthroplasty is, in the acute setting, the procedure of choice for most four-part fractures of the proximal humerus [3,4,9,13,25,27].

Indications

Most four-part fractures of the proximal humerus are indicated for hemiarthroplasty in patients who are medically suitable for such extensive surgery and are able to carry out the long rehabilitation process which is mandatory for successful outcome. In rare cases of very young patients with four-part fractures, and in a small subset of patients who have impacted four-part valgus fractures, attempts at open reduction/internal fixation with minimal hardware are indicated [6,14,15,26]. Minimal hardware is recommended so that if arthroplasty is necessary later it will preserve the remains of the soft tissue sleeve and vascularity to the humeral head [10,15,24].

Hemiarthroplasty is contraindicated in patients with medical frailty precluding surgery. It is also contraindicated in those patients whose physical or mental condition makes them unable to comply with the required postoperative rehabilitation program. Surgery is also contraindicated in alcoholics and patients with psychological impairment for these same reasons.

In the older age group indications for hemiarthroplasty are not based on chronological age, they are based on the patient's physiological age, hand dominance, and activity requirements. In the younger age group an attempt at open reduction/internal fixation is warranted to avoid prosthetic replacement and its associated complications. If AVN does occur, the tuberosities are in a more anatomic position facilitating conversion to a prosthesis.

Preoperative Assessment

As with all traumatic injuries, careful history and physical examination and appropriate radiological studies are mandatory. Careful history and physical examination is carried out to determine any co-morbid factors which might affect the surgical procedure and/or the postoperative rehabilitation process. A thorough clinical examination of the shoul-

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der is carried out to determine obvious deformity and neurovascular function. Special attention to axillary nerve function, both sensory and motor, and vascular compromise is important since many patients with complex proximal humeral fractures will have such injury. Though it should be considered that many patients with vascular injuries could have intact pulses distally due to the extensive collateral circulation around the proximal humerus. Deltoid contraction and sensory distribution may be tested and any vascular deficiency should be aggressively evaluated.

Standard X rays should include the "trauma series" which include a true anterior posterior view of the scapula, a transcapular Y view, and an axillary view. In most cases these views will supply the necessary information about this fracture complex. In some cases where the configuration and displacement remain uncertain, CT scans can be helpful, especially in distinguishing three-part and four-part fractures, or in rare cases where a four-part fracture may be indicated for open reduction and internal fixation. CT scan can also be useful in detecting any head split component which is also an indication for hemiarthroplasty.

In more complex situations scanograms may be utilized to evaluate proximal humeral bone loss and comminution and subsequent humeral length loss. This will enable the surgeon to preoperatively plan on proper humeral component placement.

Anesthesia

We utilize inter-scalene block anesthesia with supplemental general anesthesia. This allows for a decreased use of anesthetic agents, especially in the older population. It also allows for significant pain relief postoperatively so that the patient may begin early physical therapy routines. The general anesthesia component is necessary for better proximal muscle relaxation and eliminates discomfort of the patient lying in one position for extensive periods of time.

Patient Positioning

The patients are placed in a modified beach chair position with the back elevated between 30° and 45°. The head is well supported in a headrest or in a commercially available shoulder table. The patient is placed at the lateral edge of the table to allow for free mobility of the operative arm, allowing unrestricted humeral extension and adduction to facilitate the intramedullary reaming and to allow proper prosthetic component placement. The arm is appropriately prepped free (Fig. 1).

Approach

A long deltopectoral skin incision is carried out from the anterior portion of the AC joint along the coracoid process and following along the anterior deltoid distally. The surgeon develops the deltopectoral interval by identifying the cephalic vein and mobilizing it medially, and leaving it intact if possible. By leaving it attached medially it is less vulnerable to injury during the reaming of the proximal humerus. The deltoid is retracted with any available deltoid retractors or self-retainers. Care should be taken to avoid injury to the musculocutaneous nerve which crosses inferior to the coracoid. The subacromial space is cleared bluntly with gentle use of digital pressure or periosteal elevators. The proximal and distal deltoid insertion and origin are left intact and the pectoralis muscle is retracted medially. The sternal head insertion may be partially released to decrease medial pull on the proximal shaft of the humerus and allow for better exposure. The coracoid process is then identified and the clavipectoral fascia lateral to the conjoint tendon is excised. If necessary, at approximately 1 cm from the coracoid process a 1 cm tenotomy may be carried out in the conjoint tendon to decrease tension on the musculocutaneous nerve during retraction.

The fracture fragments are now exposed. The hemorrhagic bursa and fracture hematoma are debrided and excised. Incision of the leading edge of the coracocromial ligament may facilitate superior exposure and enhance visualization. In many cases the axillary nerve is now identified or palpated.

Identification and Mobilization of Fracture Fragments

The biceps tendon is isolated and identified. This is a key surgical landmark which helps locate the tuberosity fragments, since the fracture configuration is medial or deep to the exposure. The long head of the biceps tendon is found under the upper edge of the pectoralis tendon insertion and followed proximally to the rotator interval, and the rotator interval is incised to the origin of the biceps at the glenoid.

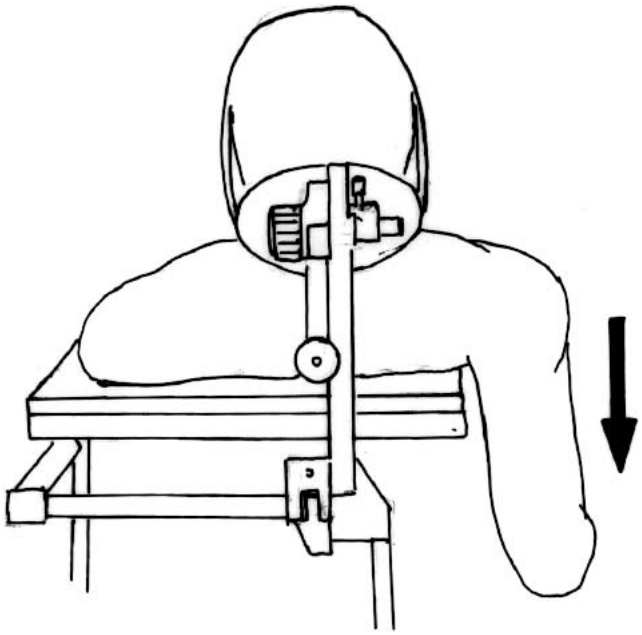

Fig. 1. Patient positioned in the beach chair position with the back at 45° and the head well-supported. The patient is lateralized on the table to allow for complete adduction and extension of the humerus.

At this point the lesser tuberosity is identified. If the tuberosities are separated by the fracture, the lesser tuberosity will be displaced medially and the greater tuberosity will be displaced posterosuperiorly. The fracture line usually travels approximately one centimeter posterior to the bicipital groove rarely directly through it. In many cases there are soft tissue attachments which must be gently freed using periosteal elevators, or, in some cases osteotomes (Fig. 2). The tuberosity fragments are often oversized and may need to be trimmed for reduction and repair later. The bone which is removed can be utilized later as bone graft during tuberosity reconstruction.

Skin hooks can be used to aid in retrieving these retracted tuberosity fragments. Once they have been retracted and pulled medially and laterally the humeral head fragment can be retrieved. It is usually found postero-inferiorly. This can be done with the aid of periosteal elevators, fracture fixation clamps, or a towel clamp. It is best to attempt to remove the head in one fragment to facilitate proper head sizing later. At this point the articular surface of the glenoid is inspected for traumatic injury or chronic changes which might necessitate the placement of a glenoid component at this time.

Tuberosity Preparation

Three #5 nonabsorbable sutures (Ethibond) are placed at the bone tendon interface between the cuff and the bony surface of the greater tuberosity. One is placed around the lesser tuberosity. These sutures can now be used for retraction and they will be later used in the tuberosity reconstruction. One should avoid placing these sutures through the osteoporotic tuberosities which may fragment under tension.

Prosthetic Insertion

With the tuberosities retracted and the humeral head removed, the intramedullary canal is now exposed. Careful attention to the appropriate height and length of the humeral shaft is made at this point. Preoperative assessment of the proximal humeral comminution is critical to allow the surgeon to place the humeral component at the proper height. Comminution of the medial humeral neck should be assessed and pieces measured to help identify the position in which the humeral component must be placed. At this point, with an idea of where the humeral component should be placed, the arm is extended and adducted to deliver the shaft anteriorly. If the pectoralis major tendons are problematic, they should be detached further. The canal is now prepared with progressive hand-held sequential reamers and rasps.

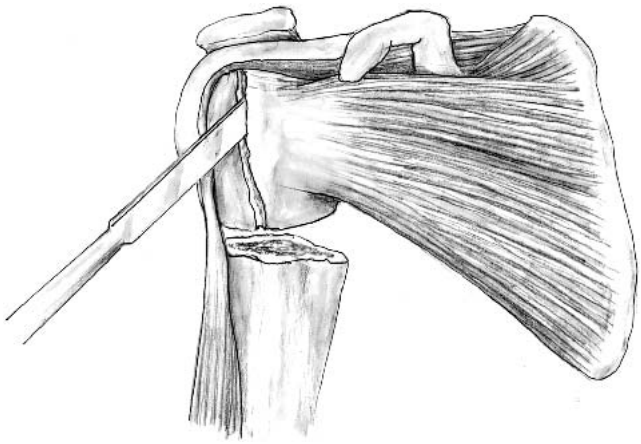

Fig. 2. Schematic picture demonstrating the anterior exposure and the identification of the long head of the biceps tendon which allows access to the fracture site. Osteotome being utilized to dissect the tuberosities.

The stem size is usually determined on preoperative radiographs and then can be evaluated intraoperatively with the humeral trial rasps which best fit the canal. The largest stem which will allow adequate seating and stability and cementing is chosen. It is critical for the surgeon to determine the appropriate version and height at this time. Version is determined by flexing the elbow to 90° and the transverse epicondylar axis of the elbow to 0°. The arm is externally rotated to a point where the humeral head would point directly to the glenoid. This is usually between 30° and 45° of retroversion. Excessive version in either direction can lead to problems with stability of the implant.

As stated above, the next most critical factor in humeral component placement is determination of proper height of the component. It is critical to have adequate tension in the deltoid myofascial sleeve. If the implant is placed in a position which is too proud, impingement and loss of motion will occur. If the implant is placed in a position which is too short, the effective length of the deltoid will be diminished and will cause a loss of power and instability (Fig. 3).

For these reasons, it is critical to appropriately place the humeral stem component. A number of different preoperative and intraoperative factors should be considered. Evaluation of preoperative X rays for bone loss and scanograms in difficult cases can give the surgeon some idea as to the appropriate stem placement. Once the stem has been chosen and the placement has been carried out with a trial prosthesis, proper humeral head and stem component placement should allow anterior and posterior translation of approximately 50%, and when the arm is pulled down the humeral head should not fall below the midpoint of the glenoid. The long head of the biceps tendon should have proper tension over the head as well. If it is difficult to hold the trial prosthesis within the canal at this time a sponge or lap pad can be placed around the prosthesis and it can be impacted into the canal, allowing for enough stability to determine the appropriate height of the component prior to final cementing (Fig. 4).

At this time the humeral head component may also be chosen to match the removed humeral head fragment. The choice of a modular head component which most closely resembles that of the head which has been removed is usually best. This will allow for proper closure of the tuberosities and rotator cuff and give the best anatomic result. A smaller head should be considered in some cases, but rarely is a larger head necessary.

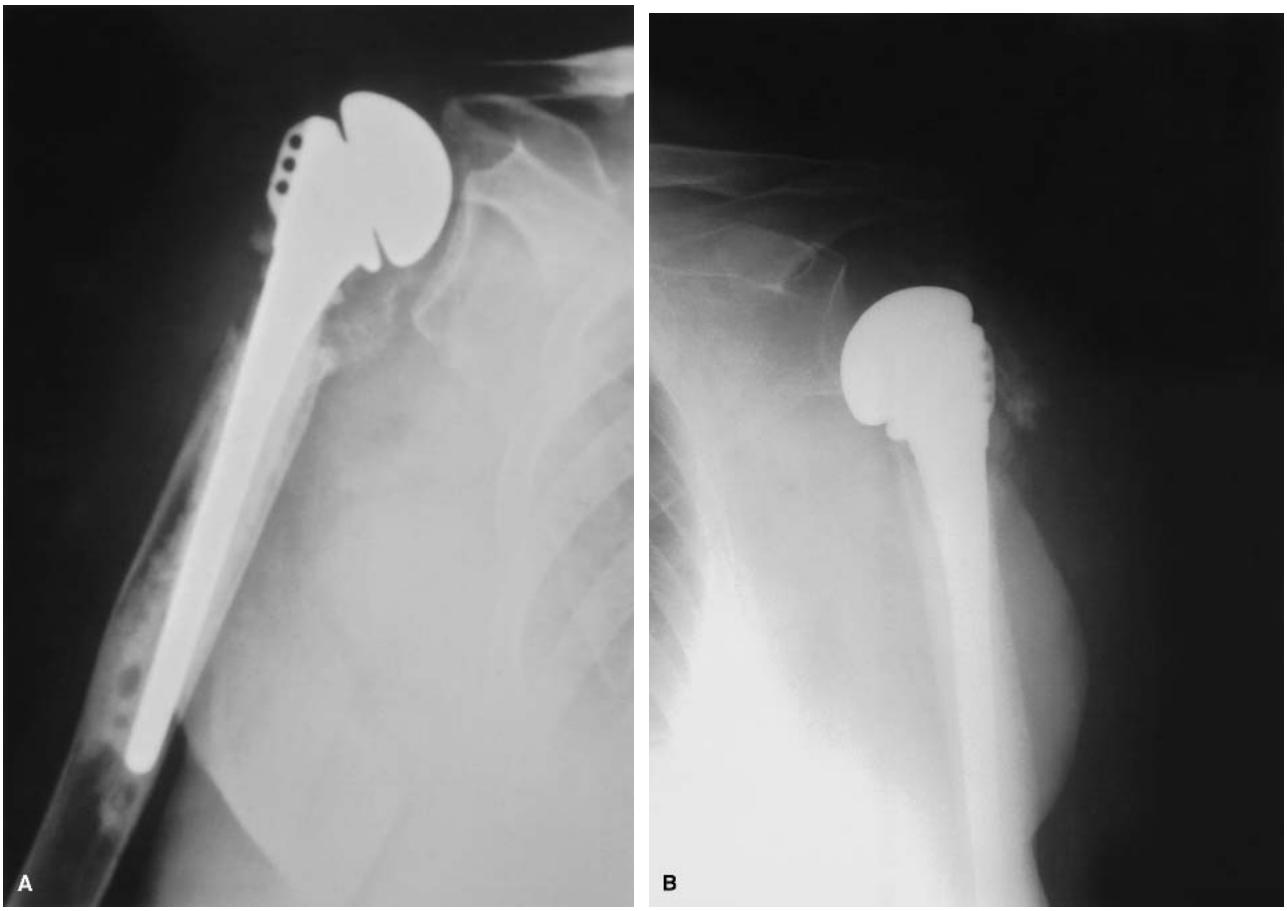

Fig. 3. (**A**) Implant placed too high. (**B**) Implant placed too low.

Prosthetic Fixation

Secure fixation of the humeral component is mandatory in fractures, and this routinely requires cement, since the porous coating on the implant does not sufficiently engage the humeral shaft because of the fracture bone loss.

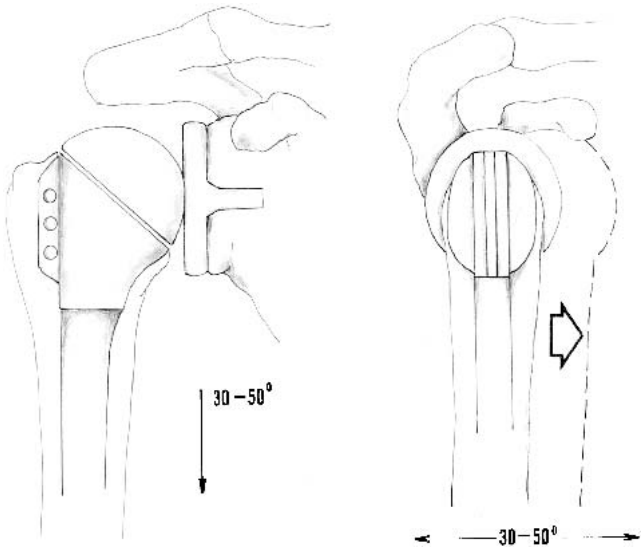

Fig. 4. After placement of the humeral component the humeral head should be able to move 50% in the anterior to posterior direction and 50% inferiorly within the glenoid without instability.

Drill holes are now placed in the shaft medial and lateral to the biceps tendon or bicepital groove; #5 sutures are placed through these holes prior to cementing for later fixation of the tuberosities. One suture is placed front to back through these holes and this will later be used as a figure-of-eight tension band. A second suture is placed through the posterior hole for longitudinal fixation of the greater tuberosity.

Proper cement technique includes complete filling of the humeral canal with minimal pressure. Distal cement plug may be used; however, pressurization should be avoided to prevent extravasation of cement through the thin posterior cortex [8].

At this point this prosthesis should be cemented in the proper height and version which has been chosen. All excessive cement must be removed from the proximal portion of the component, especially in areas of later tuberosity contact and fixation to allow tuberosity healing to the shaft.

Once the stem component has been securely cemented in the correct position, the proper-sized humeral head component is now impacted in place after thorough drying at the Morse taper.

Tuberosity Reconstruction and Rotator Cuff Repair

In addition to proper component placement, the success of the operation depends on the appropriate tuberosity re-

construction and subsequent rotator cuff function. The goal is to obtain healing of the tuberosities to the shaft and to each other, in the proper position below the top of the prosthesis.

The stay sutures previously placed at the superior, middle, and inferior supraspinatus tendon insertions of the greater tuberosity are now utilized to secure the tuberosities to the prosthetic fin and to each other and to the shaft respectively. First, the middle suture through the greater tuberosity is placed around the medial neck of the prosthesis. Next, the superior and inferior greater tuberosity sutures are placed through the respective holes in the fin and then through the lesser tuberosity at corresponding levels. The posterior longitudinal suture which was placed in the shaft of the humerus is now brought underneath these sutures and brought inside-out through the superior portion of the supraspinatus tendon above the greater tuberosity. This suture is used for longitudinal fixation of the greater tuberosity (Fig. 5).

These sutures are now tied in the following order, first to secure the greater tuberosity to the shaft and to the fin of the prosthesis, and then to secure the lesser tuberosity to the shaft and to the greater tuberosity. Bone graft is placed around the tuberosity fragments and the proximal portion of the humeral component to enhance healing.

First, the middle suture through the greater tuberosity is placed around the neck of the prosthesis and is tied. Next, the longitudinal posterior suture is tied, giving fixation of the greater tuberosity to the shaft and to the fin of the prosthesis. Prior to this fixation the lateral cortex of the proximal portion of the shaft is feathered using an osteotome or rongeur to give a better bleeding surface for fixation of the tuberosities, which often overlap by approximately 1 cm.

Once the greater tuberosity has been fixed, the lesser tuberosity is brought similarly against the fin, medially placed below the humeral head component as well. It is held with towel clamps and the front-to-back sutures are now tied in sequence. With the tuberosities now secured to the shaft and to the fin of the prosthesis, the front-to-back strands previously placed in the proximal humeral shaft are now utilized and placed in a figure-of-eight fashion through the soft tissue above the tuberosities to create a tension band effect of the tuberosities to the shaft.

In cases where it is decided to save the biceps tendon, it is now placed back in a groove and the rotator interval closed above it to prevent any subluxation. While some surgeons advocate saving the biceps tendon in the groove, we have recently studied problems in hemiarthroplasty and found a biceps tenodesis effect can occur in some cases where the tendon was saved, creating stiffness and restricted motion. For this reason, we now routinely excise the intra-articular portion of the long head of the biceps tendon and create the soft tissue tenodesis of this tendon to our tuberosity repair.

In either case, the rotator interval is now closed using #1 non-absorbable sutures.

The tuberosity reconstruction is inspected to make sure it

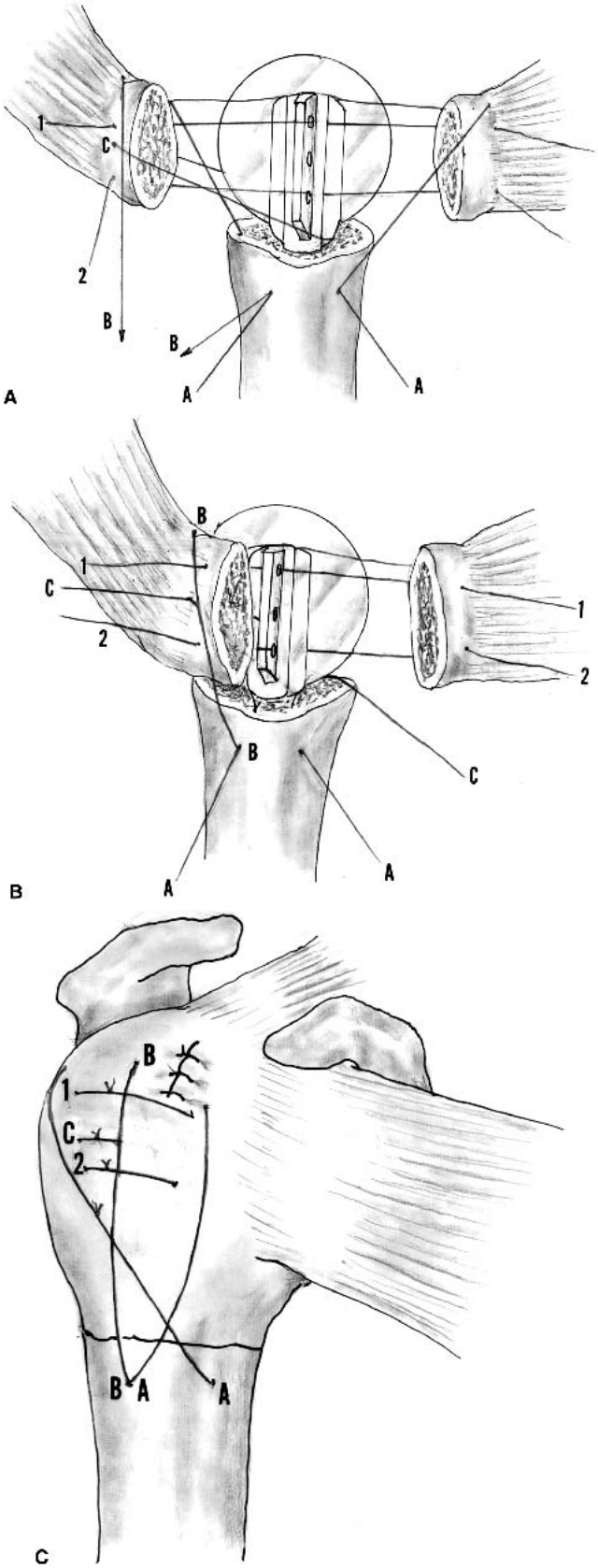

Fig. 5. (**A**) Schematic representation of the technique of tuberosity reconstruction with the sutures in place (see text). (**B**) Positioning in the greater tuberosity below the top of the prosthesis to the shaft utilizing the middle transverse suture around the neck of the prosthesis (C) and the posterior longitudinal suture (B). (**C**) Schematic representation of the tuberosities repaired.

moves as solidly as one unit and to determine the parameters of safe range of motion which afford this stable configuration. These ranges of motion should allow clearance of the acromion in abduction at 90° and allow for at least 45° of external rotation. Forward elevation should be well above shoulder height. Noting this range of motion enables the surgeon to properly plan the postoperative rehabilitation program with the physical therapist.

Tuberosity position is also critical. The tuberosities must be placed below the top of the head of the prosthesis and should be placed in a position which creates normal humeral offset as described by Rietveldt to ensure proper deltoid function after arthroplasty [22]. Recent studies by Cuomo et al. confirm that the tuberosities must be placed below the top of the humeral head component [7]. In their series those tuberosity reconstructions that were placed 5 mm to 1 cm below the top of the humeral head component had statistically significant better results than those tuberosities placed immediately below the humeral head or those which were placed above the humeral head. Placement of tuberosities above the humeral head leads to impingement (Fig. 6). Component design changes in many of the second- and third-generation implant systems have improved the surgeon's ability to reproduce the anatomic offset in these reconstructions.

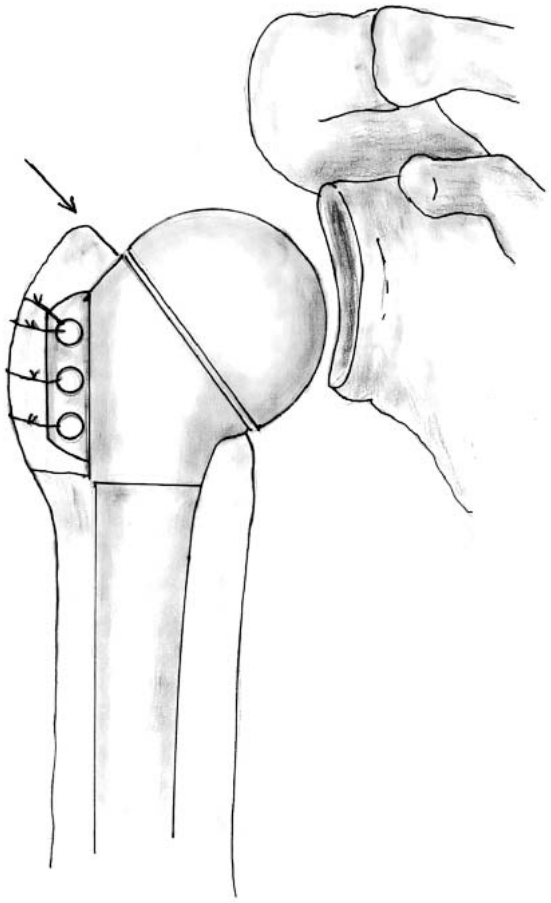

Fig. 6. Schematic diagram of a tuberosity reconstruction placed above the top of the humeral component leading to outlet impingement.

Closure

Hemovac drains are routinely placed in the subacromial space. The deltopectoral interval is closed and a continuous subcuticular skin closure or interrupted skin closure using sutures or staples is carried out. The patient is placed in a sling and swathe and taken to the Recovery Room for postoperative X rays.

Postoperative Rehabilitation

Successful hemiarthroplasty for four-part fractures depends upon a proper rehabilitation program [9,19,27]. Namely a physician-directed program which begins immediately after surgery and stresses the importance of early passive mobility to prevent adhesions. A sling is used for 4–6 weeks except during exercises. During the first 6 weeks only passive exercises are allowed. Passive range of motion exercises in the supine position and gravity-assisted pendulum exercises are instituted initially. The goal during this time is to achieve 140° of elevation in the scapular plane and 30–35° of external rotation.

This passive phase continues until there is clinical and roentgenographic evidence of tuberosity healing. At this point, isometric rotator cuff and deltoid exercises and active-assistive elevation is initiated. At 8 weeks, active elevation and gradual stretching to regain full range of motion are encouraged. Early strength training against gravity and activities of daily living are started at this time.

At 3 months, strength training is fully initiated. This includes resistance strengthening for the rotator cuff utilizing rubber tubing and light weights. Strengthening exercises should include scapular rotation exercises and deltoid strengthening exercises. These should be continued for up to 1 year. Range of motion exercises and stretching should also continue for up to 1 year as functional improvement can be expected during this time.

Complications

There are a number of reported complications which can occur after hemiarthroplasty for proximal humeral fractures [1,3,5,8,9,13,25,27]. The overall rate of complications has been reported as high as 35% [1,25]. While infection and neurovascular complications have been rarely reported, technique-related complications are the most common causes of poor result. Technique-related complications include instability due to component malposition and rotator cuff insufficiency due to failure of tuberosity reconstruction. Recently scarring of the long head of the biceps tendon has been reported as a cause of restricted motion and stiffness [12].

Instability

Placement of the humeral component in a position which is either too high or too low will lead to various forms of instability. Implants which are placed too high will lead to superior instability, leading to secondary impingement and

further tuberosity failure [8,9,11,13]. Implants which are implanted too low will lead to poor tension in the myofascial sleeve, leading secondarily to inferior subluxation and loss of function of the rotator cuff even in the face of a good tuberosity reconstruction.

Excessive humeral component retroversion, or even anteversion, can also lead to instability. While this complication is rare, excessive retroversion leaves the implant susceptible to posterior instability or restricted external rotation.

Tuberosity Reconstruction Failure

To regain proper rotator cuff function, the tuberosities must heal to the shaft of the humerus as well as themselves and around the prosthesis. In addition, the tuberosities must heal in the proper position below the humeral head. Failure of healing or malposition will lead to rotator cuff insufficiency and clinical failure. Tuberosities which heal above the humeral head component will cause impingement.

If nonunion occurs, then the rotator cuff insufficiency will ensue. If the secondary rotator cuff failure occurs, then poor function will result. There are many causes for tuberosity failure, mostly related to technique. The tuberosities must be fixed to themselves and the shaft utilizing proper suture technique. Bone graft should be included and the tuberosities should be allowed to heal before active motion is begun.

Tuberosity failure is therefore the result of poor technique in terms of placement and fixation or due to exuberant or excessive physical therapy before the bone is healed. In any case, tuberosity failure is a severely disabling complication which restricts range of motion, stability, and function.

Biceps Tenodesis Effect

Recently we have reported a group of patients who have stiffness postoperatively after hemiarthroplasty for complex fractures [12]. A number of such patients have undergone arthroscopy and were noted to have a tenodesis effect of the long head of the biceps tendon which had scarred into the rotator interval and/or rotator cuff repair. For this reason, we now advocate biceps tenodesis at the time of our initial arthroplasty. In those cases where there is severe stiffness postoperatively this complication should be considered as the cause of restricted motion, particularly if it is an external rotation and abduction. Arthroscopic debridement was helpful in a number of our patients in this series.

Results

Historically the results of hemiarthroplasty treatment for complex fractures including four-part fractures have been mixed [1,3–6,9,13,17,19,25,27]. A few authors have reported results similar to those of Neer's original article [19]. Others have reported more disappointing results [1,13,25,27].

In our own series we had 85% good and excellent results of hemiarthroplasty utilizing sound surgical techniques and appropriate physiotherapy [9,17]. In this study and a second one on chronic malunions we found that the results were better in patients younger than 70 and in those cases in which hemiarthroplasty was carried out in under two weeks from the injury [9,10,17]. These findings have been confirmed by others [21,23].

Most of the failures in reported series were felt to be of technical errors at the time of surgery. These technical errors consisted of component malposition, tuberosity malposition, and tuberosity reconstruction failure.

Summary

Hemiarthroplasty for four-part fractures of the proximal humerus is the standard of care in most patients who are medically stable and are able to undergo the extensive physiotherapy that is required. Hemiarthroplasty in this difficult set of patients is technically demanding and requires a meticulous attention to surgical detail. Proper component positioning, proper tuberosity reconstruction, and appropriate physician-directed physiotherapy is mandatory for successful result.

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