Unconstrained Shoulder Arthroplasty for Treatment of Proximal Humeral Nonunions

Surgical Technique

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Introduction

Anatomic unconstrained arthroplasty for the treatment of proximal humeral nonunion is challenging and may require management of rotator cuff tearing or scarring, glenohumeral instability, shoulder capsule fibrosis, poor bone quality and bone defects, and glenohumeral arthritis and may require internal fixation and bone-grafting for stimulation of healing¹.

Proximal humeral fractures are common injuries, especially in elderly patients with poor bone quality. The treatment of these fractures can be challenging, and limited functional results of both operative and nonoperative modalities have been reported. The development of a nonunion can contribute to poor outcomes. Historically, the results of open reduction and internal fixation of proximal humeral nonunions has been complicated by high rates of nonunion, osteonecrosis, and hardware failure^{2,3}. Additionally, internal fixation and bone-grafting does not address the presence of arthritic conditions or joint contractures. Anatomic arthroplasty is commonly used in the treatment of proximal humeral nonunions. However, high rates of unsatisfactory results, especially with regard to functional outcomes, have been reported with that procedure. Reverse shoulder arthroplasty is an option for elderly or low-demand patients but not for younger patients who wish to remain active or those with good rotator cuff muscles and humeral tuberosities. Despite the recognized limitations of anatomic unconstrained arthroplasty for the treatment of proximal humeral nonunions, it continues to remain a treatment option.

The following description of the surgical technique consists of seven key steps that highlight the important factors and considerations that will help to optimize anatomic reconstruction of the proximal humeral anatomy as well as tuberosity healing.

Step 1: Preoperative Planning

Obtain anteroposterior, axillary, and lateral scapular Y views of the shoulder to assess the fracture for the size and position of the humeral head, humeral shaft, and greater and lesser tuberosities as well as for fracture nonunion.

- Obtain a detailed history and perform a physical examination to assess the patient's ability to tolerate the operation as well as the potential etiology of the nonunion. Failure to recognize a metabolic bone disease or other factors that may lead to impaired bone healing will likely result in a poor outcome of the arthroplasty as a result of failure of the tuberosity repair.
- Obtain three views of the shoulder (anteroposterior, axillary, and lateral scapular Y views) (Figs. 1-A and 1-B). Assess the fracture for the size and position of the humeral head, humeral shaft, and greater and lesser tuberosities. Carefully assess for fracture nonunion as well as malunion, as many three or four-part fractures may have partial but not complete healing of all fragments.
- We routinely order a computed tomography (CT) scan with three-dimensional reconstruction, which aids in the evaluation of the size and quality of the bone fragments.
- Perform preoperative templating for the height and position of the component using the medial calcar if it is intact or using a radiograph of the contralateral shoulder.

Step 2: Positioning and Surgical Approach

In cases with substantial contracture or difficult exposure, use an anteromedial approach.

- Place the patient in the beach-chair position with the head elevated approximately 60°. Position the entire scapula on the operative side free from the edge of the table. In many cases, fluoroscopy can be helpful in the reduction of the tuberosities and assessment of humeral component height. If you expect to use fluoroscopy, position the patient to allow for appropriate views without obstruction.
- Use a standard deltopectoral approach, keeping the skin incision lateral to the coracoid and away from the axilla (Fig. 2). The cephalic vein can be retracted with the pectoralis or deltoid, according to your preference.
- In cases with substantial contracture or difficult exposure, use an anteromedial approach, which involves mobilization of the anterior aspect of the deltoid from the lateral aspect of the clavicle and anterior aspect of the acromion, to facilitate visualization. Repair the deltoid back to the clavicle and acromion at the conclusion of the operation. In our experience, the anteromedial approach has been a valuable tool in difficult cases and has not resulted in increased morbidity.
- After entering the deltopectoral interval, fully develop the subdeltoid space down to the insertion on the humerus and up into the subacromial space. Mobilize the conjoint tendon to expose the subscapularis tendon. Identify the long head of the biceps tendon, perform a soft-tissue tenodesis to the pectoralis tendon, and excise the intra-articular segment.

Step 3: Fracture Mobilization, Contracture Release, and Articular Assessment

For three and four-part fractures, secure the tuberosity fragments with strong sutures and then mobilize them from the articular fragment and the humeral shaft.

- In cases of isolated surgical neck nonunion, perform a subscapularis tenotomy 1 cm medial to the insertion on the lesser tuberosity and tag the tendon for later repair (Fig. 3). Then split the rotator interval to the level of the

glenoid to expose the glenohumeral joint. Release the subscapularis from the contracted joint capsule and the subcoracoid adhesions for mobilization to allow repair at the conclusion of the procedure.

- For three and four-part fracture nonunions, secure the tuberosity bone fragments with strong nonabsorbable sutures placed at the insertion of the rotator cuff tendons (Fig. 4). Then fully mobilize the tuberosity fragments from the articular fragment and the humeral shaft. An osteotomy may be necessary, depending on the degree of healing and the position of the tuberosities. Following mobilization of the tuberosity fragments, remove the humeral articular surface and size it for the humeral head prosthesis.
- The rotator cuff is often contracted with fibrosis forming to the underlying joint capsule. Releases are often needed to allow for anatomic reduction of the tuberosity fragments. Free the lesser tuberosity with the subscapularis from the rotator interval as well as the underlying joint capsule. An anterior capsulotomy is often sufficient, but in cases of severe contracture a capsular excision may be required. Identify the axillary nerve at the inferior margin of the subscapularis muscle and protect it during the capsular release to prevent injury. Then mobilize the subscapularis from the coracoid anteriorly and superiorly and from the glenoid neck posteriorly. Releasing the rest of the rotator cuff on both the articular and the bursal surface is often required to allow for full mobilization of the fracture fragments.
- Clean the fracture nonunion sites to healthy bone surfaces, and remove any fracture callus or fibrous tissue from the glenoid cavity. Inspect the glenoid for cartilage damage or bone loss or deformity. In most cases, the articular surface is well preserved. In cases with substantial glenoid cartilage damage, consider implantation of a glenoid component or reaming of the glenoid. If there is substantial bone loss or deformity of the glenoid, the results of anatomic arthroplasty can be compromised.

Step 4: Humeral Preparation and Trial Reduction (Fig. 5)

The tuberosity bone fragment should be reduced to the prosthesis with positioning 6 to 10 mm below the top of the humeral head component.

- Prepare the humerus using circular reamers of increasing sequential diameter up to cortical

contact. Then place the appropriately sized cement restrictor, and trial the humeral component. It is imperative to use a system that has a dedicated fracture stem with a narrow metaphyseal segment with a bone ingrowth surface and holes for suture fixation of the tuberosity fragments in cases in which a tuberosity osteotomy is performed.

- The ability to trial and adjust the height and version of the component will help in the accurate reproduction of the patient's anatomy. Determining the height and version of the component can be very challenging as anatomic landmarks are often lacking. An intact medial calcar helps greatly in orientation of the components. When this bone is not present, assess the height using the insertion of the pectoralis tendon, which has been shown to average 5.64 cm from the top of the humeral articular surface⁴. The tuberosity bone fragment should be able to be reduced to the prosthesis with positioning 6 to 10 mm below the top of the humeral head component.
- Contact between the tuberosities and the humeral shaft is also imperative for bone healing. When there is bone loss from the tuberosities, you can place the humeral component in a slightly lower position to allow for osseous contact with the humeral shaft. Fluoroscopy can be helpful in the assessment of the tuberosity reduction and orientation.
- Actual trialing should reveal a full range of motion with no dislocation or subluxation, 40% to 50% posterior subluxation with a posteriorly directed force and immediate snap-back to the glenoid, and 20% inferior translation with axial force. Start the trialing of different humeral head sizes with the size match to the patient's anatomy, but do not be afraid of increasing or decreasing the head size as needed on the basis of the mechanics of the shoulder.

Step 5: Humeral Component Insertion

Fixation of the humeral stem usually requires cement, but avoid cement in the area of the tuberosity nonunion to help prevent necrosis of the bone resulting in further nonunion.

- Once the trialing is completed and the appropriate implants are selected, mark the height and orientation of the trials. Many implant instrumentation systems have markings on the trials that match those on the prosthesis to aid in this task and a rod on the humeral stem inserter that can be adjusted in degrees and ref-

erenced to the flexed forearm to measure the amount of retroversion desired (typically 30°).

- Fixation of the humeral stem in a patient with nonunion usually requires cement. Prior to cementation of the humeral stem, drill holes 3 to 4 cm distal to the fracture and place heavy nonabsorbable sutures for later use during the tuberosity repair. Use a third-generation cementation technique with a cement restrictor and antibiotic-impregnated cement. Avoid cement in the area of the tuberosity nonunion to help prevent necrosis of the bone resulting in further nonunion of the tuberosity bone fragments.
- After cementation of the humeral stem, reduce the tuberosities to the prosthesis. It is important that there is contact between the bone of the tuberosity fragments and the humeral shaft to allow for healing of the tuberosities.
- Trial the humeral heads once again to ensure appropriate alignment and shoulder mechanics as previously described. Then insert the final humeral head component.
- Now turn your attention to the tuberosity repair.

Step 6: Tuberosity Fixation and Bone-Grafting (Figs. 6 and 7)

To achieve tuberosity healing in anatomic alignment, reduce the tuberosities anatomicallly followed by bone-grafting and rigid fixation.

- The most common limitation following hemiarthroplasty for proximal humeral fracture nonunion is failure of the tuberosities to heal in anatomic alignment. There are several steps that can help achieve this goal, as outlined below.
- Reduce the tuberosities anatomicallly at the time of surgery, keeping the greater tuberosity 6 to 10 mm below the top of the humeral head and at the same time keeping bone contact between the tuberosities and the humeral shaft.
- Perform bone-grafting of the tuberosities using local bone from the excised humeral head.
- Perform rigid fixation of the tuberosities to avoid displacement or motion that will result in a persistent nonunion. There are many methods for tuberosity fixation in hemiarthroplasty for proximal humeral fractures, but three basic steps should be followed:
 - Attach the tuberosities to the prosthesis.

- Horizontally compress the tuberosities to the prosthesis and each other.
- Finally, vertically compress the tuberosities to the humeral shaft.
- In patients with an isolated surgical neck nonunion in whom the tuberosities were not fractured or have healed in acceptable alignment, affix the proximal segment (head) to the distal segment (meta-diaphyseal part of the humerus) by passing the prosthesis through both medullary canals and applying compression on implant insertion after performing a subscapularis tenotomy (Fig. 3). In these cases, perform the humeral head osteotomy through the anatomic neck and prepare the proximal and distal segments as you would in a standard shoulder arthroplasty. At the time of implantation, reduce the proximal and distal segments and insert the prosthesis to allow for fixation of the fracture nonunion. You can add vertical compression sutures to compress the proximal segment to the distal one. This results in excellent fixation of the nonunion, the healing of which can be aided with grafting with local bone from the humeral head (Fig. 8).

Step 7: Closure and Postoperative Rehabilitation

Patients use a shoulder immobilizer for six weeks, begin formal physical therapy at two to four weeks, and initiate a shoulder strengthening program at about ten to twelve weeks.

- At the conclusion of tuberosity fixation, take the shoulder through a range of motion to confirm absence of movement between the tuberosity bone fragments and the prosthesis and humeral shaft.
- Following tuberosity fixation, close the rotator interval laterally and reinforce the biceps tenodesis as needed. Carefully assess for impingement of the tuberosities on the acromion or the coracoid process and perform acromioplasty or coracoplasty as needed. Address any soft-tissue contractures prior to closure to prevent excessive postoperative stiffness.
- Place a drain in the subdeltoid space and perform closure using heavy absorbable sutures in the deltopectoral interval and skin closure with buried absorbable sutures.
- Place the shoulder in a shoulder immobilizer. While in the hospital, the patient receives antibiotic prophylaxis for twenty-four hours post-

operatively and begins physical therapy on the first postoperative day. Initial therapy consists of pendulum and active range of elbow, wrist, and hand motion exercises.

- Patients are discharged from the hospital after pain is adequately controlled and they are able to complete required activities of daily living. They wear the immobilizer for six weeks, and formal physical therapy is begun at two to four weeks depending on the degree of shoulder contracture at the two-week follow-up visit.
- After six weeks, use of the immobilizer is discontinued and active range of shoulder motion is permitted, but instruct the patient to avoid lifting more than 1 to 2 lb (0.5 to 0.9 kg). Initiate a shoulder strengthening program once there is evidence of tuberosity healing, which typically occurs at about ten to twelve weeks postoperatively (Fig. 9).

Results

The management of proximal humeral nonunion is challenging, and historically results have shown reasonable pain relief with limitations in function. We noted similar results in our recent study of sixty-seven patients with a mean duration of follow-up of nine years⁵. Pain scores on a 10-point scale improved from a mean of 8.3 points preoperatively to a mean of 4.1 points at the time of the most recent follow-up. Five of six patients with severe pain postoperatively had tuberosity nonunion at the time of final radiographic follow-up. The mean satisfaction score, on a 10-point scale, was 5.7 points at the time of the most recent follow-up. Seven of eight patients with a poor satisfaction score had nonanatomic healing of the tuberosities at the time of final follow-up.

The average preoperative active elevation and external rotation were 46° (range, 0° to 130°) and 26° (range, -15° to 100°), respectively. At the time of the most recent follow-up, these values had improved to 104° (range, 0° to 180°) of active elevation and 50° (range, -20° to 105°) of external rotation. Active elevation was ≥90° in forty-six patients (69%).

Use of the Neer rating revealed an excellent or satisfactory result in thirty-three patients (49%). The factors associated with an unsatisfactory Neer rating or a reoperation in the remaining thirty-four patients included patient-reported dissatisfaction (twenty-seven), a limited range of motion (twenty-three), and moderate or severe pain (nineteen).

Final radiographic follow-up showed that seventeen tuberosities had healed in an anatomic position (<5 mm of displacement), eighteen were malunited (≥5 mm of displacement, with seven having

proximal displacement and eleven, distal displacement), eighteen were not united (two had been followed between three and six months and could be classified as delayed unions), and fourteen had resorbed or had been previously resected. Of thirty-two patients with initial anatomic tuberosity fixation, seventeen went on to have anatomic healing, eight had nonunion, three had malunion, and four had resorption at the time of the most recent follow-up.

There were fourteen complications in twelve patients. Anterosuperior instability developed in seven patients and was recognized within the first six months in five. Instability was associated with tuberosity nonunion (four), tuberosity resorption (one), or a rotator cuff tear (two). A repeat operation to address tuberosity nonunion was performed in two patients, with one obtaining anatomic healing and a satisfactory outcome and the other developing a fibrous union and an unsatisfactory outcome. Rotator cuff repair was attempted in two patients, with augmentation with a fascia autograft in one of them. Both went on to have an unsatisfactory outcome with persistent instability, pain, and limited motion. There were two deep infections; one was treated with component removal and staged reimplantation and the other, with resection arthroplasty. Additional complications included a hematoma and wound necrosis; both were treated with surgical debridement and healed without additional problems.

What to Watch For

Indications

- Pain (primary indication) and limited function (secondary indication) associated with nonunion of a three or four-part proximal humeral fracture
- Surgical neck nonunion with poor bone quality or bone loss in the humeral head
- Proximal humeral nonunion with arthritis of the glenohumeral joint
- Osteonecrosis or collapse of the humeral articular surface
- Adequate bone stock of tuberosities to allow for repair

Contraindications

Absolute

- Infected nonunion of a proximal humeral fracture. Treatment of the infection with surgical debridement, an antibiotic spacer, and intra-

venous antibiotics must precede definitive management with arthroplasty.

- Medical conditions that prevent use of general anesthesia. If a patient is not medically able to tolerate surgery, then continued symptomatic management of pain is the treatment of choice.

Relative

- Poor tuberosity bone quality or resorbed tuberosities. In the face of irreparable tuberosities, a reverse total shoulder arthroplasty may provide better results.
- Advanced glenoid bone loss or deformity, as reverse total shoulder arthroplasty or resection arthroplasty may provide better results.
- Inability to comply with postoperative rehabilitation, which is essential for a successful functional outcome. Patients who are unable to comply should probably not undergo the procedure.
- Young or active patients with adequate bone to allow for fixation and no arthritis. Such patients should undergo an attempt at open reduction and internal fixation with bone-grafting.

Pitfalls & Challenges

- Anatomic restoration of humeral anatomy. Bone loss and fracture malunion can result in difficulty in reestablishing a normal anatomic orientation of the proximal part of the humerus.
- Tuberosity fixation and healing. Poor bone quality, vascular compromise of the bone fragments, and contracture of the rotator cuff musculature can result in difficulty in achieving anatomic reduction and healing of the tuberosity bone fragments.
- Contracture of the joint capsule and rotator cuff can result in a limited functional outcome even if there is anatomic healing of the fracture nonunion.

Clinical Comments

- The treatment of proximal humeral nonunions is challenging as a result of multiple factors, including poor bone quality and biology as well as soft-tissue contractures and muscle atrophy. Neer originally described hemiarthroplasty for the treatment of the complex four-part proximal humeral fracture. In his report he described the results as "satisfactory but imperfect."⁶ The results of hemiarthroplasty for proximal humeral nonunions can be described in the same way. Evaluation of the lim-

ited available literature on this topic reveals that the majority of patients have a decrease in pain but persistent functional limitation^{5,7-9}. The difficulty in achieving anatomic healing of the tuberosity bone fragments has been identified as the key factor limiting functional outcomes. In our series⁵, we encountered the same difficulties. The use of synthetic bone grafts and bone morphogenetic proteins has shown promise in the treatment of nonunions of the tibia. The use of these as an adjunct to improve tuberosity healing of proximal humeral nonunions has yet to be determined but may be effective in improving outcomes.

- With improvements in fixation techniques involving locking plates and structural bone-grafting, there have been improved results with open reduction and internal fixation of proximal humeral nonunions, with healing rates of up to 90%². In patients with adequate bone stock

and vascularity of the humeral articular surface, open reduction and internal fixation with bone-grafting may be the best treatment option. However, many nonunions are associated with poor vascularity of the humeral articular fragment and a cavitation of the bone, limiting the ability to proceed with open reduction and internal fixation.

- The indications for reverse total shoulder arthroplasty are rapidly expanding. Use of this procedure for complex proximal humeral fractures in the elderly population has shown promising results^{10,11}. Its role in the treatment of proximal humeral nonunions has yet to be clearly delineated, but it may result in improved outcomes in elderly or low-demand patients. Further investigation is required before reverse total shoulder arthroplasty can be considered superior to hemiarthroplasty for the treatment of proximal humeral nonunions.

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Figures

Fig. 1-A

Preoperative anteroposterior radiograph of a fifty-eight-year-old woman, six months following a three-part proximal humeral fracture treated nonoperatively, demonstrating a nonunion of the surgical neck and malunion of the greater tuberosity.

Fig. 1-B

Axillary view of the patient shown in Fig. 1-A. This view also demonstrates evidence of glenohumeral arthritic changes.

Fig. 2

The deltopectoral surgical incision starts at the lateral aspect of the coracoid process and extends distally and laterally away from the axilla. The axillary nerve can be found at the inferior border of the subscapularis in the subcoracoid region and on the deep surface of the deltoid approximately 4 cm distal to the lateral aspect of the acromion. Understanding of the anatomic location and careful retraction of the nerve are important, but full exposure is not required.

Fig. 3

In a patient with a surgical neck nonunion, subscapularis tenotomy is performed 1 cm medial to the insertion on the lesser tuberosity to allow access to the glenohumeral joint.

Fig. 4

The greater and lesser tuberosity fragments are secured with heavy sutures and mobilized to expose the fractured humeral articular surface in patients with a four-part fracture. In those with a three-part fracture, the greater or lesser tuberosity must be osteotomized from the articular surface.

Fig. 5

Anatomic positioning of the humeral component should be confirmed with use of trial components with the goal of having the top of the humeral articular surface 6 to 10 mm above the top of the greater tuberosity and maintaining contact between the tuberosity and the humeral shaft. Rotational version of the humeral component should be confirmed with use of an alignment rod on the stem insertion handle, which is aligned with the forearm to confirm placement of the humeral stem in 30° of retroversion.

Fig. 6

Top image: Tuberosity repair is initiated with anatomic reduction of the tuberosity bone fragments. **Middle image:** Fixation of the tuberosities to the prosthesis is then performed with heavy nonabsorbable sutures through the suture holes on the prosthesis. **Bottom image:**

Horizontal compression sutures are then placed around the tuberosities and the medial neck of the prosthesis, providing compression of the tuberosities to the prosthesis and each other.

Fig. 7

Left image: Vertical compression sutures are placed through drill holes in the humeral diaphysis 3 cm distal to the fracture and then looped around the insertion of the rotator cuff musculature on the greater and lesser tuberosities to compress the tuberosity construct to the humeral shaft. **Right image:** Bone graft on the humeral head is packed around the junction between the tuberosity fragments and the humeral shaft.

Fig. 8

A technique for isolated surgical neck nonunions uses the prosthesis to skewer the proximal bone fragment with the intact tuberosities, and fixation to the shaft is obtained with the humeral prosthesis.

Fig. 9

Two-year follow-up radiograph showing a total shoulder replacement with bending of the humeral stem to accommodate the tuberosity malunion at the time of surgery. The surgical neck nonunion has gone on to union, and there is no evidence of loosening or displacement of the humeral or glenoid component. The patient reported no pain and had active elevation of 140°, active external rotation of 70°, and an excellent result according to the modified Neer rating.

Fig. 1-A

Fig. 1-B

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9