CHAPTER

3

The Basic Shoulder Arthroplasty: Simple Shoulder Replacement for the Generalist

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ABSTRACT

Shoulder arthroplasty was first introduced through the developments of Dr. Charles Neer and over the past decade has seen several advancements. Improved recognition and training have heightened the awareness of arthroplasty as a treatment alternative both for surgeons and patients. The addition of reverse shoulder arthroplasty has been the driving force behind the explosive growth of arthroplasty and is now performed more often than anatomic shoulder arthroplasty. Although revision shoulder arthroplasty is primarily of interest to the subspecialist, it is a skill sought by the general orthopaedic surgeon. It is important for the orthopaedic surgeon to be knowledgeable about the planning, necessary skills, and management of basic shoulder arthroplasty.

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Introduction

Modern shoulder arthroplasty in the United States is derived largely from the pioneering work of Dr. Charles Neer, who released the first shoulder humeral prosthesis in 1951.[1] Shoulder arthroplasty continued as a niche procedure for several decades but has seen explosive growth in the United States in the past decade. The number of shoulder arthroplasty procedures has doubled in the past 10 years in the United States. In 2000, 1,800 artroplasties were performed, and this number increased to 45,000 in 2015. Last year, 55,000 shoulder artroplasties were reported in the United States.[2]

Several factors have contributed to this explosive growth of shoulder arthroplasty. Improved awareness, training, and outcomes have heightened the recognition of arthroplasty as a treatment alternative both for surgeons and patients. However, the largest driver of growth has been the addition of reverse shoulder arthroplasty (RSA). The number of RSA procedures now outpaces anatomic shoulder arthroplasty. In 2018, of the 55,000 shoulder arthroplasties performed in the United States, 28,000 were RSAs.[2]

Revision shoulder arthroplasty has continued to be primarily of interest to the subspecialist. However, the incidence of shoulder arthroplasty has increased to a level that it is a skill sought out by the general orthopaedic surgeon. It is important for the orthopaedic surgeon to review surgical indications, preoperative planning, surgical technique, and postoperative management of the basic shoulder arthroplasty.

Planning for Shoulder Arthroplasty

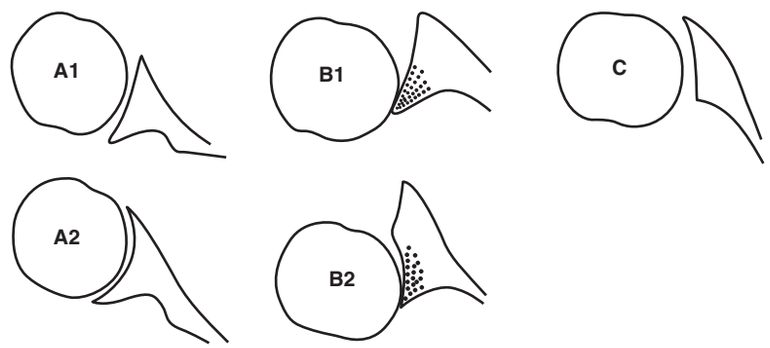
Preoperative planning for shoulder arthroplasty begins with a thorough physical examination, evaluation of plain radiographs, and advanced imaging including MRI or, more typically, CT scan. Understanding and managing glenoid morphology and deformity is a critical aspect of the surgical plan. Virtual planning and patient-specific instrumentation facilitate pathology recognition as well as accurate implant sizing and placement.

Physical Examination

Anatomic total shoulder arthroplasty (TSA) is indicated for glenohumeral osteoarthritis with an intact and functioning rotator cuff. Before considering shoulder arthroplasty, the physician should start with a thorough physical examination with both shoulders exposed. The examination begins with visual inspection. Special attention should be paid to prior surgical incisions, bony deformities, skin lesions, or atrophy. Active and passive range of motion (ROM) should be documented in forward elevation, abduction, external rotation with the arm at the side, and internal rotation. Patients with severe contractures will require more extensive soft-tissue releases. These measurements can help the surgeon assess patient function and plan appropriate surgical releases. Strength of the deltoid and the rotator cuff should be documented and compared with that of the contralateral side.

Imaging

All shoulder evaluations should include a complete radiographic series including AP, Grashey, scapular Y, and axillary views. Radiographs should be evaluated for fractures, loose bodies, joint-space narrowing, superior migration of the humeral head, size and location of osteophytes, humeral deformity, humeral head size, glenoid wear, and humeral head subluxation. Glenoid morphology is often categorized according to the Walch classification,[3] which helps the surgeon to identify glenoid wear patterns (**Figure 1**). Complete evaluation of bony morphology and glenoid bone stock can often be difficult on radiographs.[4] In these cases, CT can be a useful tool and allows for



Walch Classification of Glenoid Wear	
Type A	Concentric wear, no subluxation of humeral head (HH), well centered • A1 no or minor central erosion • A2 deeper central erosion, line connects anterior/posterior glenoid rims and transects HH
Type B	Biconcave glenoid, asymmetric glenoid wear and head subluxated posteriorly • B1 posterior joint narrowing (no posterior bone loss), osteophytes, subchondral sclerosis • B2 posterior rim erosion, retroverted glenoid • B3 monoconcave, posterior wear, at least HH subluxation >70% OR retroversion >15%
Type C	• C1 Glenoid retroversion >25°, regardless of erosion

FIGURE 1 An illustration showing the Walch classification.

the most accurate assessment of glenoid morphology, version, and degree of humeral head subluxation. The authors of this chapter routinely use CT scans for assessment of the glenoid and for virtual planning. If there is suspicion of rotator cuff tear on examination, ultrasonography or MRI can be used.

Surgical Planning

Whether using radiographs or CT scan, the surgeon should take note of anatomic variations to properly plan the surgery. The surgeon can calculate glenoid version using the method defined by Friedman et al,[5] glenoid inclination as defined by Maurer et al,[6] concentricity or eccentricity of the glenoid, and the amount of humeral head subluxation.[7] These measurements have been shown to be more accurate using three-dimensional imaging and are typically performed referencing the scapular plane and glenoid face. The humeral head diameter can be estimated on two-dimensional CT reconstructions by estimating the anatomic neck distance. Particular attention is directed to B2 or biconcave glenoids because these have been shown to have higher rates of complications including glenoid implant loosening and instability.[3] Several techniques have been applied to attempt to manage abnormal glenoid morphology. Partial version correction, with eccentric reaming, is commonly used. This is accomplished by matching the version of the paleoglenoid and slightly medialized reaming to create a concentric surface. Although partial version correction has been shown to be a viable option,[8,9] it is not without limits. It is generally accepted that attempting to correct greater than 15° of retroversion may result in overmedialization of the glenoid center of rotation or implant penetration of the glenoid vault.[10] Medialization of the glenohumeral articulation can result in instability, abnormal kinematics, and early glenoid implant loosening. At the most basic level, the surgeon should plan glenoid preparation to determine the angle of reaming the glenoid face, version correction, and possible augmentation.

Virtual planning is the most advanced and interactive way to case plan. Several implant system-specific software programs are now available. With virtual planning of TSA, it is important to first establish treatment goals. Goals for the glenoid implant include complete backside support, avoiding reaming beyond the subchondral plate, appropriate peg placement, avoidance of vault penetration, and appropriate implant size and rotation. Correction of version and inclination can also be integrated into the plan. If these parameters are not able to be met, advanced techniques or utilization of RSA can be considered. Another advantage of virtual planning software is the ability to integrate the use of patient-specific instrumentation (**Figure 2**), which has been shown to maintain a high level of accuracy in implant positioning;[10-12] other options include computer navigation—and soon, robotics.

Anatomic TSA

Glenohumeral osteoarthritis is a common degenerative condition that results in significant pain and functional limitations. Anatomic TSA is a reliable surgery that results in excellent pain relief and significant improvement in function and quality of life.[13,17] Intraoperative soft-tissue management including appropriate releases of the capsule and mobilization of the subscapularis are critical for adequate glenoid exposure and to restore the normal horizontal force couple of the shoulder. It is imperative that the surgeon is familiar with the characteristics and limitations of the implant system, as many have unique features that can be used to address specific intraoperative pathology. In general, it is advisable to start with easier cases (A1 and A2 glenoids) and progress to more difficult cases (B2, B3, D, and C glenoids; large muscular males) as more experience with the procedure is acquired (**Figure 3**). A systematic step-by-step approach is critical when performing shoulder arthroplasty to ensure reliable and reproducible exposure, soft-tissue management, and implant placement, while minimizing complications.

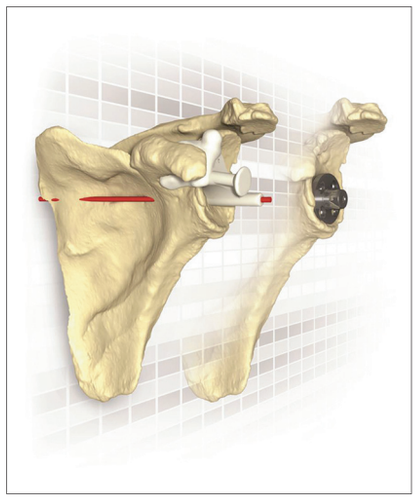


FIGURE 2 A computer navigation-generated jig for placement of the central screw of a reverse shoulder arthroplasty baseplate. (Copyright DJO Global, Inc. 2020.)

Surgical Technique

Anesthesia, Patient Positioning, Skin Preparation

Patients undergoing TSA may choose general anesthesia with or without additional regional anesthesia based on shared decision making with the surgeons and the anesthesiologist. The patient is positioned in a semirecumbent (beach-chair) position with the back elevated 30° to 40°. The surgical extremity must have completely unencumbered extension, adduction, and external rotation to ensure adequate exposure for humeral preparation. All bony and neurologic prominences are adequately protected and passive ROM is evaluated. The skin may be prepped with a combination of betadine and 2% chlorhexidine gluconate in 70% isopropyl alcohol (ChloraPrep). Recent literature suggests that the addition of 3%

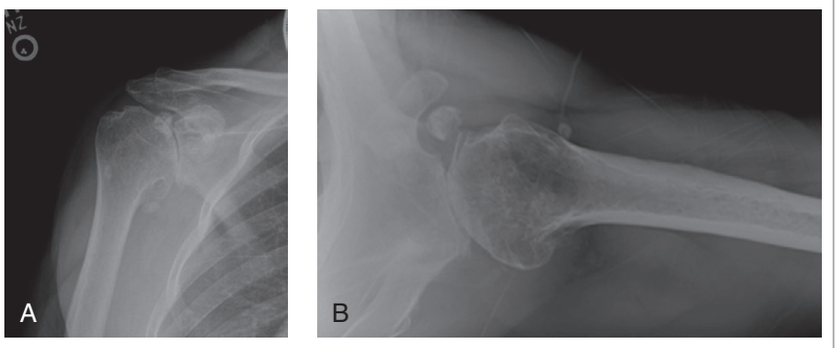


FIGURE 3 AP (**A**) and lateral (**B**) radiographs of advanced glenohumeral osteoarthritis with loss of the joint space, osteophyte, and loose body formation.

hydrogen peroxide reduces the burden of *Cutibacterium acnes* in skin cultures by 50%.[18]

Deltopectoral Approach

The arm is positioned in slight flexion, abduction, and external rotation with the use of an arm holder to reduce the soft-tissue tension surrounding the shoulder. A 10- to 12-cm incision is made over the deltopectoral interval heading toward the deltoid insertion. Dissection is carried deep through the subcutaneous fat. The cephalic vein is identified and retracted laterally with the deltoid, and the deltopectoral interval is developed down to the level of the clavipectoral fascia. Mobilization of the subdeltoid and subacromial space is necessary to ensure proper humeroscapular mobility, particularly if the patient has had prior shoulder surgery. A self-retaining retractor such as a Kolbel is helpful for soft-tissue retraction. A partial release of the upper 1 to 1.5 cm of the pectoralis major tendon may be performed to aid in exposure if necessary.

The clavipectoral fascia is incised just lateral to the conjoined tendon and the release is carried proximally to the level of the coracoacromial ligament, which is preserved. The plane between the conjoined tendon and the subscapularis is developed bluntly to identify the axillary nerve and possibly the musculocutaneous nerve. The Kolbel retractor is repositioned deep to the conjoined tendon after identifying the axillary nerve. The arm is externally rotated to expose the anterior humeral circumflex artery and veins, which are either ligated or coagulated. The arm is brought back to neutral rotation, and the biceps tendon may be identified, with tenodesis and proximal excision performed.

Subscapularis Reflection and Capsular Release

Subscapularis management is a critical component of TSA. The subscapularis can be reflected and repaired anatomically, unless prior surgery has resulted in subscapularis shortening (ie, Magnuson-Stack or Putti-Platt procedures). Reflection by either tenotomy, peel, or lesser tuberosity osteotomy may yield equivalent results,[3-5] but the preference of the chapter authors is to perform a lesser tuberosity osteotomy. A small wafer of the lesser tuberosity and the subscapularis are reflected off the underlying anterior capsule (**Figure 4**), which is then released from the anatomic neck.

Progressive flexion and external rotation of the humerus will tension the inferior capsule as the release is carried distally. The inferior release is always carried past the 6-o'clock position to ensure adequate glenoid exposure, taking care to protect the axillary nerve.

Humeral Osteotomy

The humeral head is delivered into the wound with adduction, extension, and external rotation of the arm. A Brown deltoid retractor placed superiorly coupled with a large Darrach retractor medially and a blunt Hohmann retractor inferomedially aid in exposure. All osteophytes are removed to identify the native anatomic neck and humeral version. Removing the osteophytes at this stage also improves glenoid exposure by narrowing the humeral head diameter. The humerus is then cut with an oscillating saw in the patient's native version (**Figure 5**). The humeral head is then sized because in many systems this dictates glenoid sizing.

Glenoid Exposure

The arm is positioned in moderate abduction, slight external rotation, and minimal extension to begin glenoid exposure. After identifying and protecting the axillary nerve, the anterior and inferior capsule is excised. The remaining posterior capsule is released, unless there is greater than 25% posterior subluxation. A posteriorly placed Fukuda retractor, an anteriorly placed reverse double-prong Bankart retractor, and a posterosuperiorly placed blunt Hohmann retractor aid in exposure. The entire labrum and biceps anchor are completely excised. The glenoid is then prepared based on the specifications of the implant system, and the final implant is placed (**Figure 6**).

Humeral Preparation

Preparation of the humerus is unique to the specific system. Selecting the appropriate humeral head size and position can be aided by offset or eccentric head options. If the ideal humeral head is between two sizes, it is preferable to undersize the implant if it does not adversely affect the stability of the joint. Once a head size and orientation

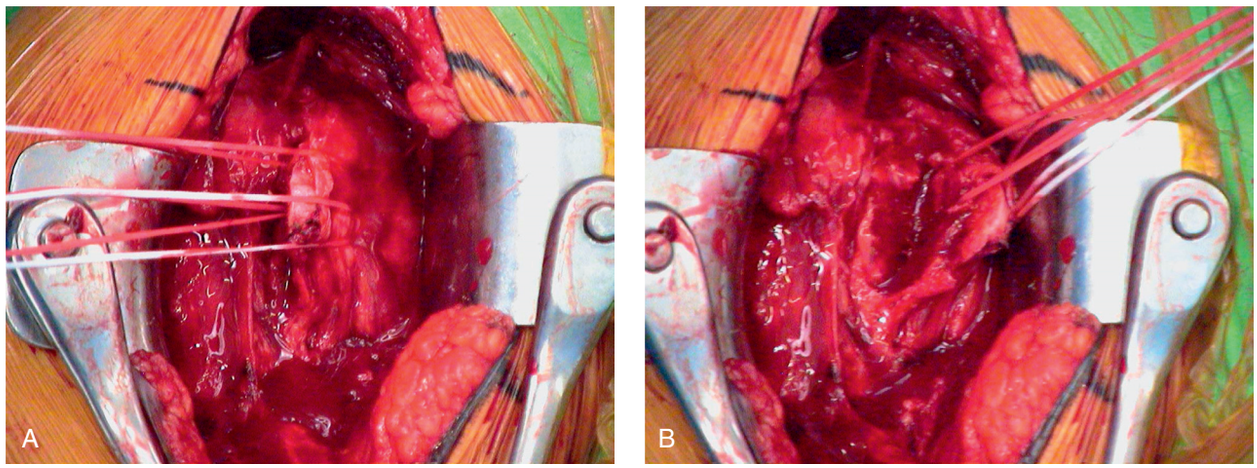


FIGURE 4 **A**, A lesser tuberosity osteotomy was performed and three heave nonabsorbable sutures are placed around the bone-tendon interface . **B**, Eversion of the lesser tuberosity osteotomy demonstrates the muscular portion of the subscapularis and the inferior capsule attached to the humerus.

is determined, stability and soft-tissue tension are evaluated to ensure appropriate implant selection and placement.

Subscapularis Repair/Closure

The subscapularis can be repaired in a variety of ways depending on the method of reflection. The preferred method of the chapter authors of lesser tuberosity osteotomy repair is similar to the description by several authors[14-16] with several heavy nonabsorbable sutures placed through the lateral aspect of the osteotomy site and tied over a bone bridge lateral to the bicipital groove. One or two nonabsorbable stitches are placed between the anterior supraspinatus and the upper subscapularis to close the rotator interval and protect the subscapularis repair (**Figure 7**). The wound is irrigated and closed in a layered fashion.

Rehabilitation

The chapter authors' protocol for rehabilitation after anatomic TSA is based on the passive ROM and overall condition of the shoulder at the end of the surgical procedure. This protocol is flexible and should be tailored to the specific pathology of the patient. It is particularly important to assess the subscapularis repair after prosthetic implantation such that passive ROM following surgery does not overtension the repair before adequate healing. Typically, immediate passive ROM within the tension-free range obtained at the end of the surgical procedure is allowed (ie, 40° of external rotation and 140° of forward elevation). Patients who have greater stiffness preoperatively

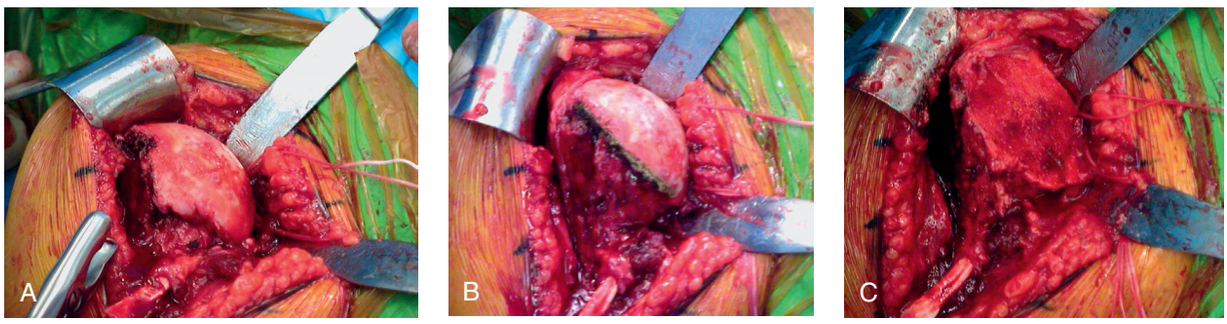


FIGURE 5 **A**, The humerus is delivered into the wound and exposure is aided by a series of different retractors. **B**, Humeral osteophytes are removed to delineate the anatomic neck. **C**, The humeral osteotomy is made along the anatomic neck replicating the patient's native version.

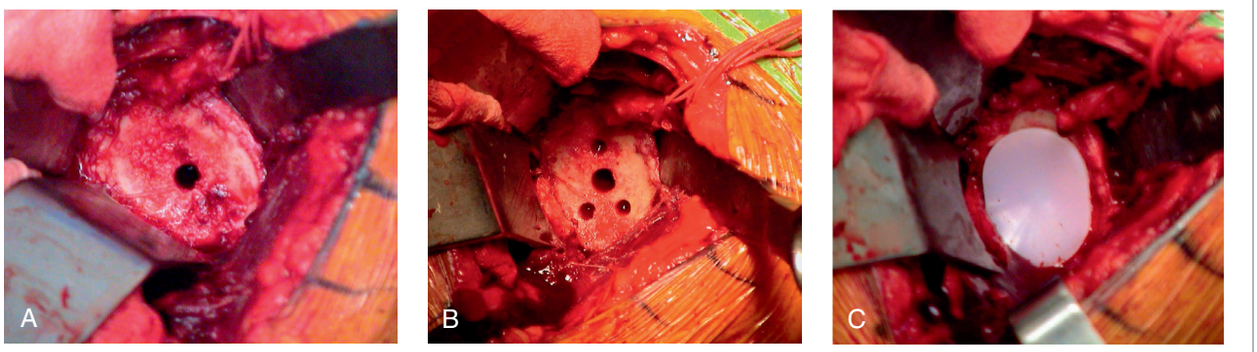


FIGURE 6 **A**, Glenoid exposure is obtained. **B**, The glenoid is then reamed, and the central and peripheral holes of the pegged glenoid implant are drilled. **C**, The final implant is secured into place.

generally have more liberal postoperative passive ROM restrictions to maintain the motion obtained at the time of surgery. At 2 weeks postoperatively, passive external rotation is maintained to 40°, while passive forward elevation is increased to 170°. At 6 weeks, the abdominal compression test is evaluated and overhead pulley exercises are initiated along with generalized stretching and strengthening exercises.

Primary RSA

RSA was initially proposed to improve outcomes of patients with pseudoparalysis. The increasing familiarity with the procedure along with the favorable outcomes[19] has expanded the initial indications.[20,21] Currently RSA is commonly used for the treatment of several complex shoulder conditions. Rotator cuff arthropathy, irreparable massive rotator cuff tears, primary osteoarthritis of the shoulder, complex proximal humerus fractures, malunions, chronic dislocations of the shoulder, and revision arthroplasty are some examples of the expansion of RSA.[22]

General surgical principles of RSA commence by placing the patient in the beach-chair position (**Figure 8**, **A**). A deltopectoral approach is essential for adequate exposure (**Figure 8**, **B**). The surgical incision is taken down to the deltopectoral fascia. The subdeltoid, subacromial, and subcoracoid spaces are released, and a bursectomy is performed. Biceps tenodesis follows. The subscapularis is released off the lesser tuberosity. At this point, the surgical assistant gently externally rotates the arm to dislocate the humeral head in an atraumatic fashion (**Figure 8**, **C**). The remaining osteophytes are removed circumferentially at the anatomic neck. Next, a humeral neck cut is performed in 30° of retroversion (**Figure 9**). A canal finder helps to identify the humeral canal, which is then sequentially broached to the desired size. A metaphyseal reamer is used until the superior edge is flush with bony cortex. The subscapularis is then tagged, and the axillary nerve is identified and palpated.

At this point, attention is paid to the glenoid. Placement of the retractors around the glenoid is key for adequate visualization. A Hohmann retractor is placed on the posterior aspect of the glenoid, and a Cobra retractor is placed on the anterior side (**Figure 10**). The capsule and labrum surrounding the glenoid are sequentially released. The inferior capsule is carefully resected while protecting the axillary nerve. A 2.5-mm drill is used to create a center hole for the glenoid baseplate. In a normal glenoid, the drill should be perpendicular to the glenoid face and tilted inferiorly 10° to 15°, allowing preferential reaming of the inferior aspect of the glenoid (see **Figure 10**, **B**). Next, a 6.5-mm tap is used to guide sequential reaming for baseplate preparation (**Figure 11**). Insertion of the glenoid baseplate follows. Peripheral locking screws are inserted unless there is insufficient bone, in which case nonlocking screws can be angled to improve purchase on the bone. Multiple sizes of glenospheres are available, and the selection is influenced by patient size, degree of soft-tissue contracture, quality of glenoid bone, and the expected degree of instability (**Figure 11**). The glenosphere is placed on the baseplate via a Morse taper. A retaining screw is then placed into the central hole of the glenosphere to augment the attachment to the baseplate.

Attention is then turned back to the humerus. The proximal humeral reaming is completed, and the humeral socket trial is chosen from a variety of sizes depending on the soft-tissue balancing and degree of instability (**Figure 12**, **A**). A reduction is performed, and impingement and stability are assessed throughout the passive ROM of the shoulder (**Figure 12**, **B**). Once appropriate implants are selected, transosseous sutures are placed in the lesser tuberosity of the humerus for future repair of the subscapularis (**Figure 12**, **C**). A dressing is applied, and an immobilizer is placed on the arm. Standard radiographs are obtained immediately postoperatively.

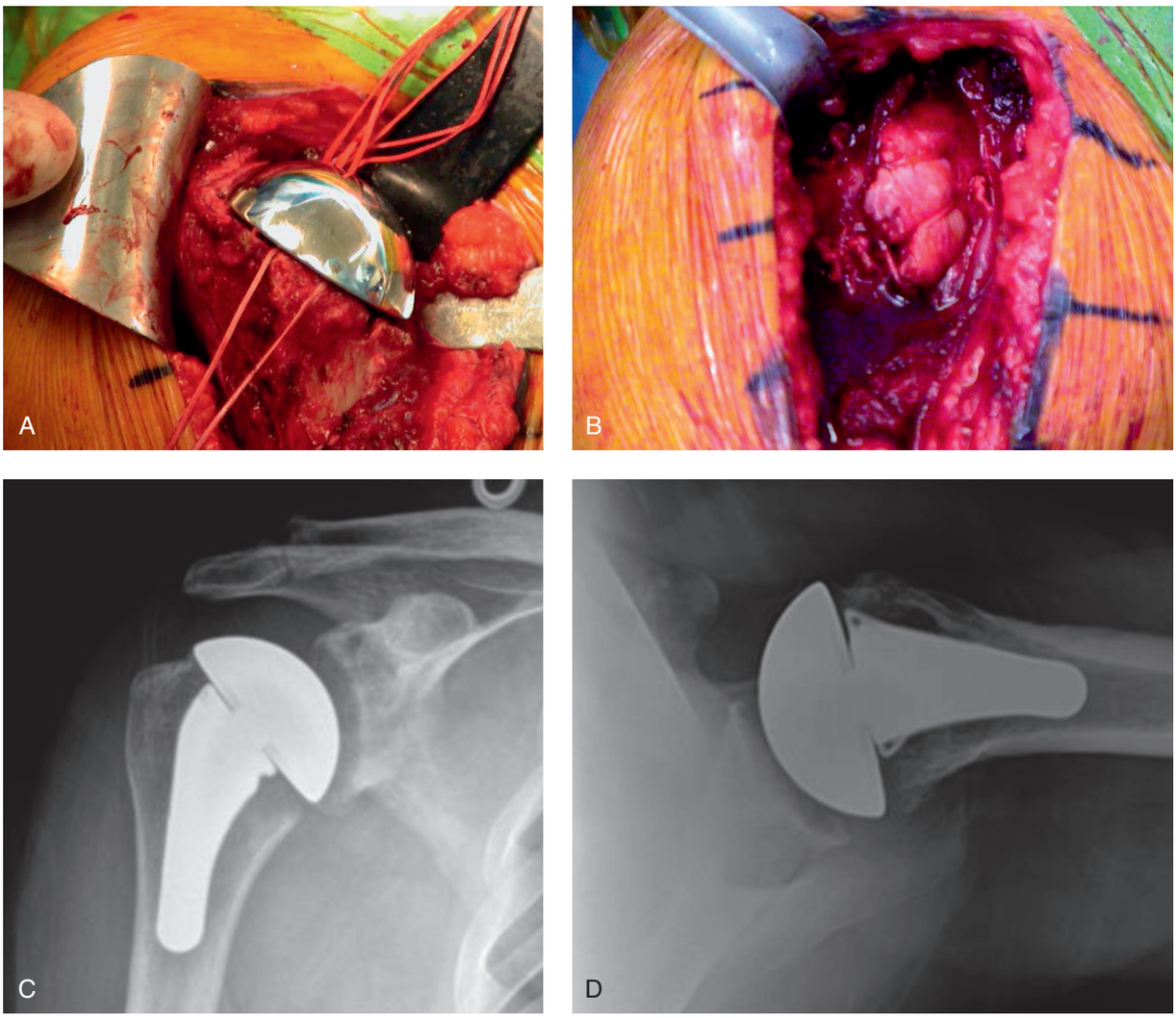


FIGURE 7 **A**, The final humeral implant is impacted into place. **B**, The lesser tuberosity osteotomy is repaired with several heavy nonabsorbable sutures. Postoperative AP (**C**) and axillary (**D**) radiographs demonstrate excellent positioning of the prosthesis.

RSA for Osteoarthritis With Intact Rotator Cuff

The outcomes for osteoarthritis with an intact rotator cuff are equivalent between anatomic TSA and RSA.[22-26] However, eccentric glenoid wear patterns, excessive retroversion, and humeral head subluxation have been identified as factors for early failure after TSA.[7,26-28] Because of the increase in articular constraint with RSA, it is an attractive option in cases where recentering the glenohumeral articulation may be challenging.

The recommendation for RSA in a case of osteoarthritis with intact rotator cuff is warranted in a patient in whom trialing of the glenoid implant yields an unnecessary rocking-horse effect or, as previously mentioned, Walch C patterns, eccentric wear, or subluxation of the humeral head that are associated with a higher failure rate.[7,26-28] It is advisable for any surgeon planning for a TSA to have the RSA set ready in case an intraoperative finding alters the initial strategy.

Massive Irreparable Rotator Cuff Tear Without Glenohumeral Arthritis

When conservative treatment does not provide the outcomes the patient expects, several options are available. These include arthroscopic débridement

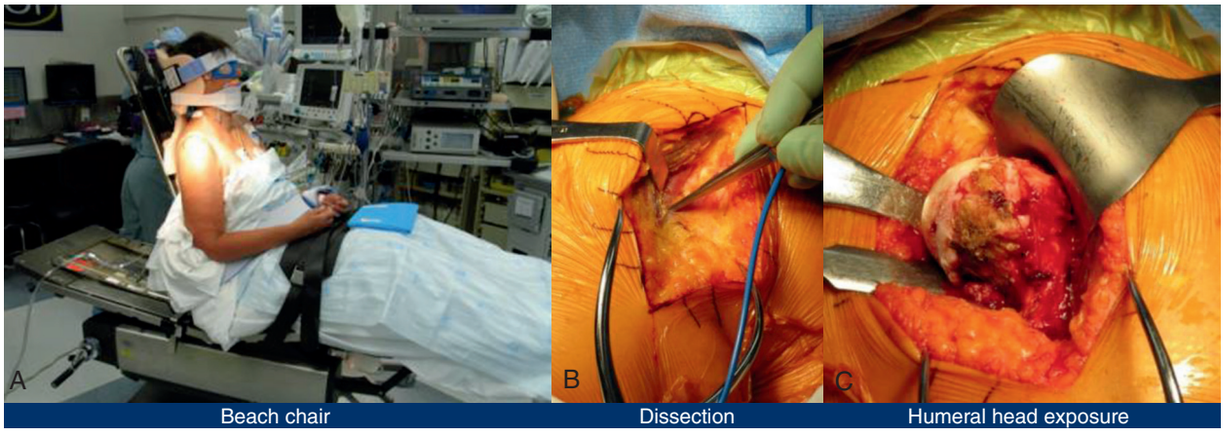


FIGURE 8 Positioning and initial dissection.

with biceps tenotomy or tenodesis, partial or complete arthroscopic rotator cuff repair, tendon transfers, superior capsule reconstruction, and RSA. All are valid options with advantages and disadvantages. The most critical decision in this subgroup of patients is to clearly identify which patient may benefit from an RSA.

RSA can reduce pain and improve function in patients with shoulder pain and superior escape in the setting of an irreparable rotator cuff tear. However, special attention is necessary for patients with preserved motion but severe pain. Mulieri et al[29] found that patients with preserved motion with more than 90° of elevation had a higher complication rate.

Similarly, Boileau et al[30,86] found that among patients who had 90%

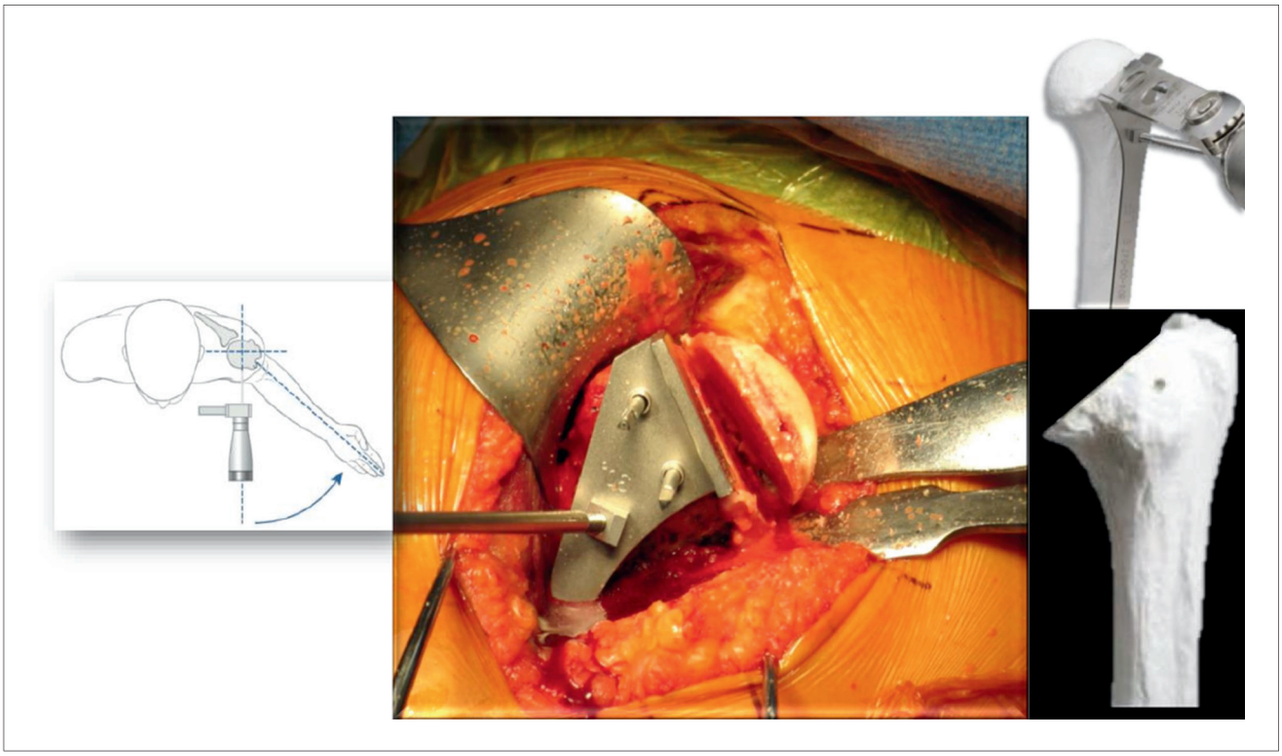


FIGURE 9 Humeral head osteotomy.

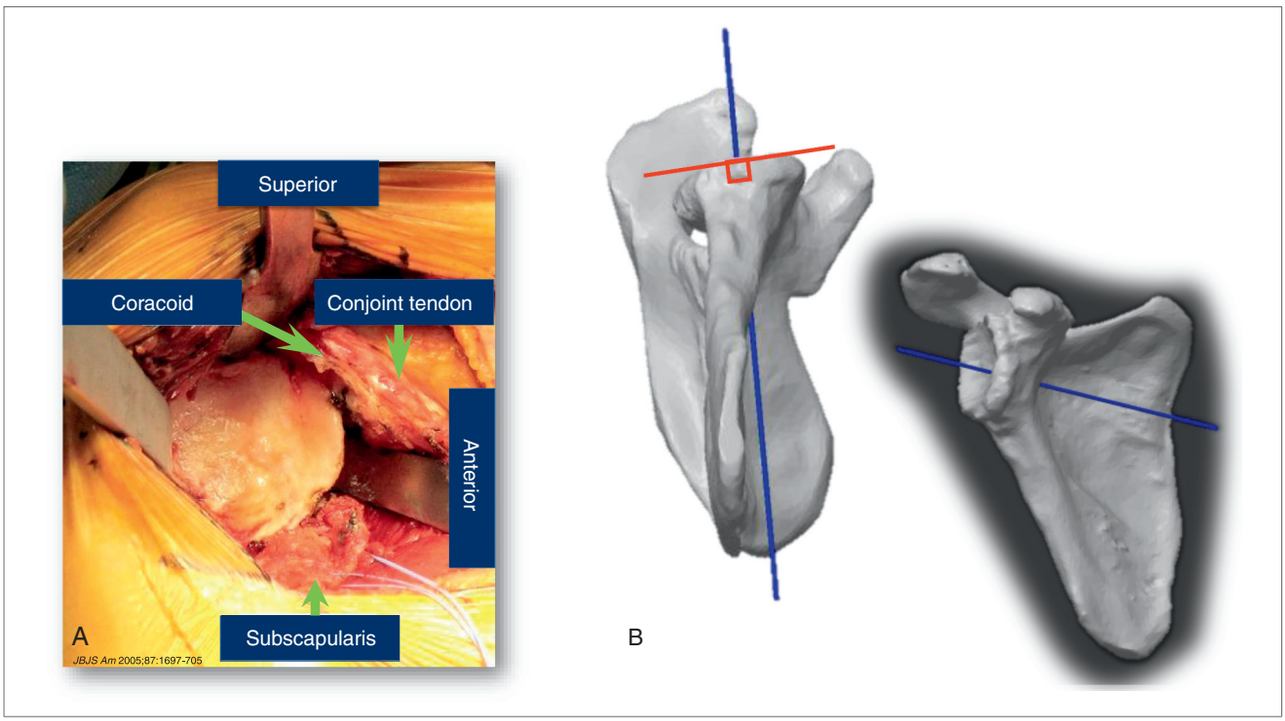


FIGURE 10 Positioning central screw. [AU20]

of preoperative elevation, anterior active elevation decreased from 146° to 122° and 27% were dissatisfied. For this reason, patients with good ROM shoulder seek symptomatic improvement through a different procedure such as débridement and/or partial or complete rotator cuff repair rather than RSA. In addition, several studies have found age younger than 65 years to be a risk factor for poor functional improvement following RSA.[49-53] In this scenario, the ideal candidate for RSA would be a patient older than 65 years with a massive irreparable rotator cuff tear and evidence of pseudoparalysis with active forward elevation less than 90°.

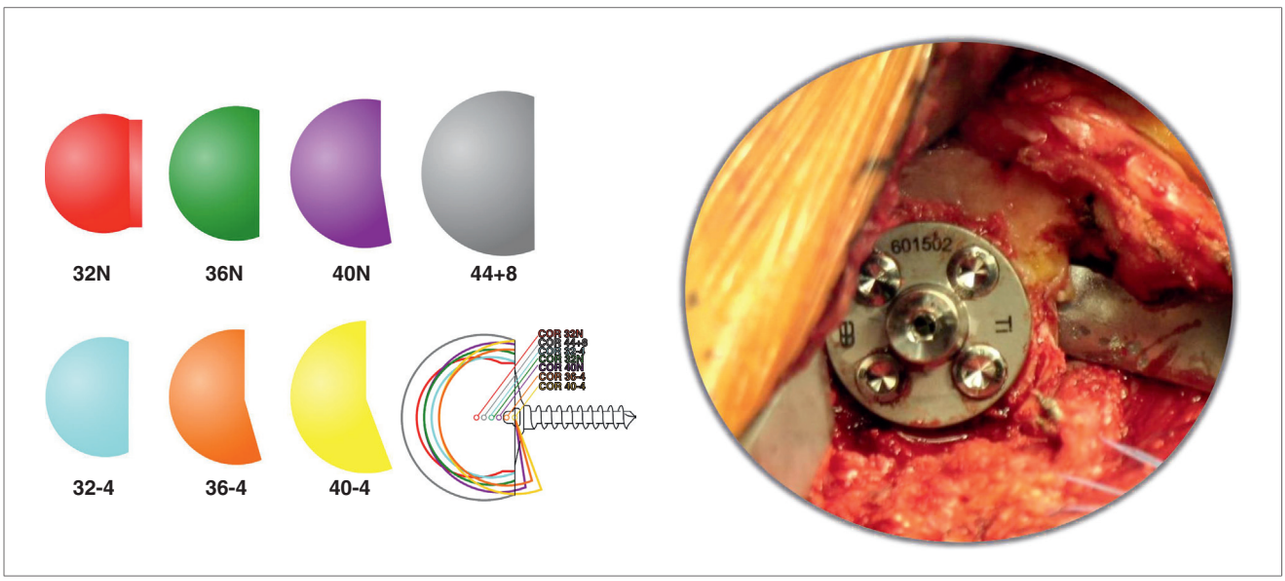


FIGURE 11 Placement of the baseplate and glenosphere.

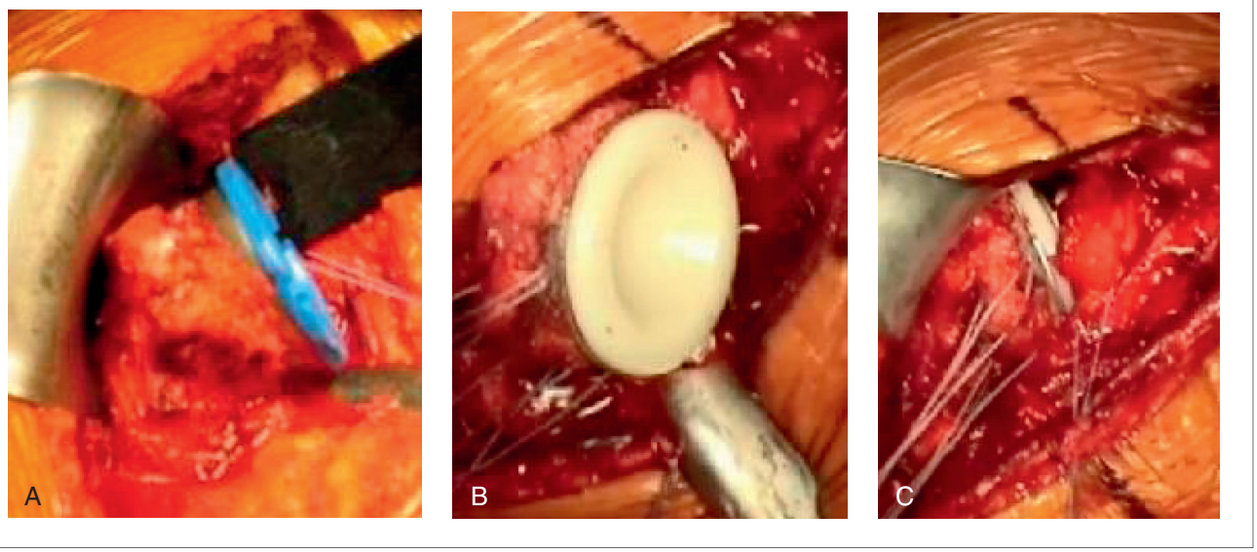


FIGURE 12 **A**, Humeral implant with trial liner. **B**, Final polyethylene liner and (**C**) reduced reverse shoulder arthroplasty.

RSA for Malunion

Literature shows acceptable results on nonsurgical treatment of displaced proximal humerus fractures.[32,33] Nevertheless, a subgroup of these patients develop intractable pain and reduced function with activities of daily living.[34] Surgical options range from broaching,[34-39] osteotomy of the tuberosity, to tuberoplasty with rotator cuff repair and subacromial decompression, to arthroplasty. Arthroplasty is indicated in cases where there is joint incongruity or head splitting fractures in older patients.

RSA for the management of malunited fractures yields favorable outcomes.[34-39] However, the dislocation rates are the biggest challenge postoperatively with a range between 20% and 30%.[19,20] Over the years certain strategies have been developed to prevent this complication.[34-40] Some authors recommend osteotomy,[34-37] whereas others encourage use of the largest glenosphere possible.[38]

The fundamentals of RSA for malunion start with scar tissue release from the subcoracoid, subacromial, and subdeltoid spaces as well as anterior and inferior capsule excision. Rather than compromise bone stock by osteotomy of the bony deformity, it is recommended to release the soft tissue to gain the appropriate exposure and/or ROM. For example, if the greater tuberosity malunion prevents adequate exposure of the glenoid, even after freeing of the rotator cuff from surrounding scar tissue, the rotator cuff should be released off the greater tuberosity with electrocautery. If this is necessary, some posterior rotator cuff is left to preserve some external rotation. Next, the humeral canal is prepared by a cemented technique. The bony deformity is accommodated by centering the socket within the deformity to minimize the distance from the bone to the socket in every direction. To accomplish this, the socket reamers are often used without the humeral trial stem, which would constrain the reamer position. Thus, the socket dictates the position of the final implant, and the stem is usually downsized so it can be freely positioned within the canal in an eccentric manner. Version of the socket is also altered to accommodate the bony deformity and always results in increased retroversion of the humeral implant beyond the standard 30° present in the system instrumentation. This version is judged intraoperatively by positioning the head cut and reamers to maintain the malunited tuberosities while minimizing excessive retroversion. No attempt is made to perform osteotomy of the malunited tuberosities or remaining proximal humerus. However, after implantation of the humeral implants, excess bone is removed by use of a rongeur to improve the impingement-free arc of motion. Templating radiographs may be the most readily available tool to assist in preoperatively determining implant position.[38] The ideal candidate is a patient with a painful malunited proximal humerus fracture with joint incongruity that a simple débridement or tuberoplasty would not improve the symptoms or ROM.

RSA for Glenoid Bone Loss

There are numerous options for patients with glenohumeral arthritis, an intact rotator cuff, and severe bone loss. Conventional TSA yields excellent outcomes in patients with glenohumeral

osteoarthritis.[4] However, the data are very compelling regarding caution when considering use of an anatomic TSA when facing severe glenoid bone loss.[22,39-44] Whether reaming to a flat surface and placing a TSA[24] or bone grafting the defect,[25] both techniques yield unacceptable high rates of glenoid implant loosening, complications, and clinical failure. Therefore, RSA is recommended for the management of primary bone loss because of an increase in articular constraint and a lower incidence of glenoid implant failure.

When electing RSA, several techniques have shown adequate results. McFarland et al[43] medialized the articular surface with the smallest size of reamer to produce a flat surface. In their study, despite medialization of the baseplate and violating subchondral bone of the glenoid vault, patients had significant improvements at minimum of 2 years in pain relief and ROM using a lateralized implant.

Preliminary reports of bone grafts were promising[7] and subsequent studies showed satisfactory outcomes.[45-50] Lorenzetti et al[45] described excellent outcomes following a lateralized primary RSA with structural bone grafting for severe glenoid bone loss. In their study, the amount of native bone contact under the glenoid baseplate was analyzed by matching the projected shape of the implant and scapula from the postoperative radiographs with a generated three-dimensional model of the preoperative scapula. The main conclusion drawn from their study is that excellent outcomes were encountered despite the degree of native bone contact under the baseplate. Intraoperatively, a different orientation of the central screw was used to increase the amount of bone captured. This alternative center line is created from the center of the glenoid surface; it passes along the axis of the scapular spine as it joins the body of the scapula.[46] After reaming, if less than 80% of the underside of the glenoid is in contact with the baseplate, either a bulk graft from the humeral head or a femoral head allograft is used. The graft is contoured and placed directly into the defect and held in place by either Kirschner wires or a 3.5-mm screw. The construct is then reamed to conformity with the tap still in place. The tap is then removed, and the baseplate is inserted. This technique demonstrates significant improvements in function, motion, and pain.[45-47]

It is important to recognize that when dealing with bone loss, an important step for a successful outcome is preoperative planning with adequate imaging. RSA, therefore, is recommended for any case of significant bone loss because of the increase in articular constraint. Moreover, the authors of this chapter advocate for bone grafting creating an alternative center line rather than reaming the native glenoid to a flat surface.

Arthroplasty for Fracture

Proximal humeral fractures continue to be challenging and still carry the reputation of the unsolved fracture. Screws, suture, intramedullary devices, and plates constitute a partial list of treatment alternatives for these fractures. The advent of locking plates for proximal humeral fractures was initially thought to be a panacea for these fractures. However, initial complication rates using locking devices when first developed were reported in 40% of cases. Complication rates have trended somewhat lower over time, and this decrease may be more because of stratification of these fractures—rather than improved surgical management.[54]

Hemiarthroplasty for Fracture

Hemiarthroplasty for proximal humeral fractures predated Neer's shoulder arthroplasty system by several decades in 1951. Although fixation of the humeral shaft to the head may be problematic, even for locking plates, hemiarthroplasty has offered secure fixation of the implant to the humeral shaft via cement fixation. Multiple authors have noted considerable variability in patient outcomes after hemiarthroplasty for fracture. Poor forward elevation in hemiarthroplasty is directly linked to failure of tuberosity healing. It has been demonstrated that the forces across tuberosities after surgical repair may exceed the stabilization offered by modern suture techniques.

Hemiarthroplasty prosthetic design changes have been implemented to address tuberosity healing. Although early designs did not show significant evolution in tuberosity healing rates, later designs have improved tuberosity healing rates.[55] However, healing rates, even after design modifications have still underperformed. It remains an open question whether newer short stems combined with noncemented technique can significantly improve tuberosity healing rates.

RSA for Fracture

RSA for fracture appeared as a response to the issues associated with tuberosity healing associated with hemiarthroplasty. Because RSA is not dependent on rotator cuff function, initial results showed improved forward elevation compared with hemiarthroplasty. Other authors also noted the decreased variability in patient outcomes associated with RSA for fracture.

Indications for RSA for fracture have expanded to encompass nearly all the original patterns treated in the past by hemiarthroplasty. Patients physiologically older than 70 years with associated three-part or four-part fractures are the largest group treated with RSA. Relative indications for RSA can include tuberosity comminution in patients with three-part or four-part fractures in their seventh decade. Although less common, anatomic neck fractures in older patients are also amenable to RSA.

The technique for RSA for fracture builds off the standard RSA and TSA technique. The deltopectoral approach discussed previously is the standard

approach for these fractures. Highlights of the surgical technique include identifying and tagging the tuberosities. With removal of the fractured humeral head, the exposure for placement of the baseplate and glenosphere is uninhibited, resulting in exceptional visualization. Placement of the baseplate follows the same principles for standard RSA, and glenosphere sizing is typically smaller in women when compared with men.

Preparing the humeral side includes reaming and broaching similar to standard RSA techniques. Typically, most humeral stems in RSA for fracture will require the utilization of cement because of the bone loss from fracture rendering the stems rotationally and translationally unstable. Drill holes are placed into the humerus for repair of the tuberosities to the stem. The implants are then trialed, assessing for stability and ROM. Many surgeons may find that utilization of the C-arm early in their learning curve is a useful adjuvant.

Final implants are then placed, cementing the stem into position as noted earlier. Repair of the tuberosities with heavy suture or surgical tape is typically used (**Figure 13**). The tuberosities are repaired to the humeral shaft through drill holes placed earlier in the procedure. The tuberosities are also repaired through the fins of the prosthesis and repaired to each other. Bone graft harvested from the humeral head is added around the tuberosity repair, and multiple techniques have been described to limit cement infiltration around the tuberosity repair.

Wound closure and postoperative management of RSA for fracture does not differ significantly from standard RSA. Because of the more extensive wound issues associated with fracture, most surgeons will delay beginning ROM work until wound healing is assessed at the first postoperative visit. In common with standard RSA, many patients undergoing RSA for fracture can use a home-based rehabilitation program in place of formal physical therapy.

Results

Controversy continues to exist regarding the role of surgical management in proximal humerus fractures. Patients who undergo RSA for fracture consistently demonstrate significant improvement when compared with their preoperative state. Given the difficulties associated with tuberosity healing after hemiarthroplasty, it is not surprising several studies have demonstrated RSA for fractures to yield superior outcomes when compared with hemiarthroplasty.[57] Although studies have shown improvement in patient outcomes for fracture managed with RSA, some studies have failed to demonstrate a significant statistical significance. The margin in some studies between showing statistical difference has been small (P = 0.007). It is likely these studies may have been underpowered, and larger studies are likely to demonstrate statistical significance.

The role of tuberosity repair has been debated in RSA for fracture. Early studies promoted excision of the tuberosities, because the authors deemed them unimportant for RSA function and noted difficulty in gaining repair around the wider humeral implants used in RSA. Studies evaluating the outcome of RSA have noted improvement in overall outcomes when the rotator cuff is repaired. Similarly, more recent studies have demonstrated improvement of RSA for fracture outcomes with repair of the tuberosities

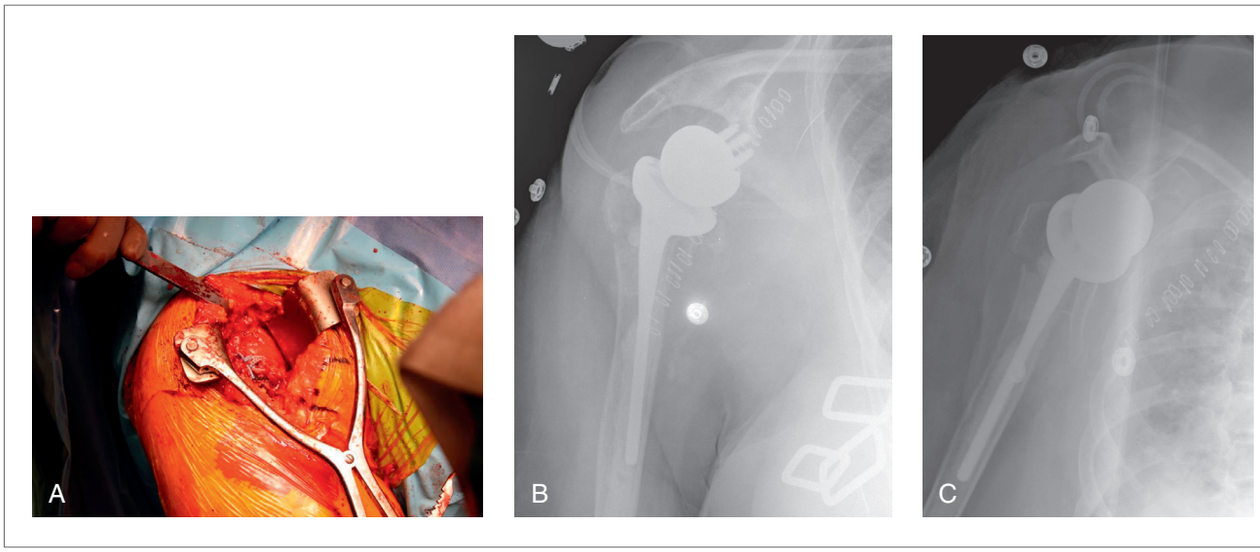


FIGURE 13 **A**, Intraoperative view of repaired tuberosities. **B** and **C**, Postoperative radiographs showing near anatomic reduction of tuberosities around reverse shoulder prosthesis.

at the time of surgery. Healing rates of tuberosities after RSA for fracture have been reported in the 84% of patients with suture and bone grafting at the time of surgery—despite the advanced age of most patients. Patients demonstrating tuberosity union exhibit greater forward elevation, external rotation, and patient satisfaction.[58]

Because failure after open reduction and internal fixation (ORIF) for proximal humeral fractures is not uncommon, RSA has been used as a salvage procedure. Recent studies have shown similar outcomes after primary RSA for fracture versus RSA for salvage of failed ORIF. However, it should be noted that RSA for failed ORIF demonstrated a significantly higher complication rate versus primary RSA for fracture.[59]

Although it appears RSA for fracture improves a patient's initial presentation, the long-term results of the procedure are largely unknown. Few studies have reported outcomes beyond a 5-year minimum. Thus, the long-term survival of the prosthesis is largely unknown. However, it appears that RSA has a good intermediate-term and long-term track record for prosthetic survival. Furthermore, given the older age of the average patient undergoing RSA for fracture, the physical demands and wear on the prosthesis are unlikely to be high.

Complications

Complications of RSA for fracture are uncommon and mirror the difficulties seen in RSA.[60] Infection, bleeding, and instability are the three most common complications associated with RSA for fracture. Management of these complications is the same as in traditional RSA (see the following section on management of complications).

Management of Complications of Shoulder Arthroplasty

TSA has proven to be a successful procedure with reliable improvements in pain and function with a high rate of patient satisfaction. Although more long-term studies need to be performed, the 20-year revision-free survivorship has been shown to be 85%.[61] As prosthetic designs improve, the focus of the surgeon should be to minimize complications and improve outcomes. The most common complications of TSA are prosthetic loosening, glenohumeral instability, rotator cuff tears, infection, and neurologic injury.[62,63]

The prevalence of glenoid radiolucencies has been reported to range from zero to 100% and increase with duration of follow-up.[64-66] Midterm outcomes of more modern prosthetic designs with enhanced fixation features have reported lower rates of radiolucencies,[67-69] but glenoid loosening continues to complicate anatomic TSA. The first step in minimizing glenoid loosening is during the exposure. Careful and systematic glenoid exposure allows the surgeon to visualize and properly place the implants. The proper approach should release the capsule off the humerus, remove osteophytes, remove the entire labrum, and selectively release capsule off the glenoid. Avoiding placement of the glenoid in excessive retroversion[26] or superior inclination[70] may limit edge loading and humeral head subluxation and decrease the risk of loosening or secondary rotator cuff failure. The surgeon should strive for 100% backside coverage of the glenoid implant while avoiding violation of the subchondral bone support, although several reports have mentioned 80% coverage to be acceptable.[9] Excessive corrective reaming, especially in the setting of eccentric wear patterns, can lead to medialization of the glenoid implant and loss of bony support. Although many prosthetic designs including metal-backed glenoids, bone ingrowth polyethylene or porous metal pegs, inlay glenoid implants, and augmented implants have been created to address this problem, long-term studies are lacking. Careful surgical technique and patient selection are the best way to improve implant survivorship. Loosening of the humeral implant is less than 1% to 2% and, if seen, should raise concerns of periprosthetic infection.

Glenohumeral instability after anatomic TSA is relatively uncommon, and typically is suggestive of rotator cuff insufficiency. Instability is defined based on the direction of pathologic humeral translation and can be anterior, superior, or posterior. Anterior instability is associated with implant malrotation, glenoid deficiency, muscle dysfunction, and, most commonly, failure of the subscapularis.[63-65] The most important step in minimizing anterior instability is meticulous management of the subscapularis. The authors of this chapter recommend a combination of bone tunnels and fixation to the stem with nonabsorbable high-strength suture. Superior instability is most commonly associated with posterosuperior rotator cuff or coracoacromial arch deficiency. Preoperative examination, imaging, intraoperative inspection, and protection of the rotator cuff throughout the case may limit this complication. Placing the glenoid implant in superior inclination, the humeral head above the rotator cuff insertion, or using an excessively large humeral head to limit the stress on the rotator cuff should be avoided. The authors of this chapter try to avoid release of the coracoacromial ligament because it functions as an important secondary restraint to dynamic anterosuperior subluxation. Posterior instability is multifactorial and likely related to excessive glenoid retroversion, muscle imbalance, and soft-tissue deficiency. Static posterior humeral head subluxation has been shown to lead to early loosening of glenoid implants, especially when a high percentage of the humeral head is subluxated posteriorly (ie, 85% to 90%). The chapter authors' preferred technique is to partially correct glenoid deformity contributing to posterior subluxation through eccentric glenoid reaming to more native version by matching the anterior paleoglenoid. Partial correction has been shown to

recenter the humeral head on the glenoid face.[73] Soft-tissue management is another way to prevent posterior instability. In cases with native posterior humeral head subluxation, the chapter authors recommend removing only 50% of the posterior labrum without release of the posterior capsule to avoid iatrogenic instability. Posterior plication sutures may be placed to tighten the posterior capsule, and these sutures can be secured to the remaining 50% of the posterior labrum. Implant position may be changed by either shifting the glenoid implant posteriorly, using an eccentric humeral head with anterior offset, or both. These implant changes allow the humerus to sit in its anatomic position while allowing a concentric prosthetic articulation.

Rotator cuff tears are extremely common even in asymptomatic shoulders and become more prevalent with increasing age.[7,74] Physical examination and imaging are crucial in detecting large rotator cuff tears before anatomic TSA. Even if a tear is thought to be unlikely, close inspection at the time of surgery is required to ensure an intact rotator cuff. The most common tear after TSA is rupture of the repaired subscapularis. Subscapularis management including release to allow full excursion and meticulous repair may help avoid this complication. Patient risk factors include smoking, diabetes, and noncompliance with restrictions. Small isolated tears of the supraspinatus have not been shown to affect outcomes of TSA, but moderate to severe fatty degeneration of the infraspinatus or subscapularis does.[76] Iatrogenic rotator cuff tears most commonly occur when cutting the humeral head. A cut that is too aggressive, too valgus, or in excessive retroversion may compromise the rotator cuff tendon insertion. Improper implant placement may also place the rotator cuff at risk. Overstuffing the joint, or placing the humeral head too high, leads to increased stress on the rotator cuff and increases the risk of failure. This can occur by using an overly large humeral head, superior placement of the humerus, and varus malpositioning of the stem.

Although infection after TSA is less than 1%,[62,77] it remains one of the most feared complications. The most common organisms include *Staphylococcus* and *C acnes*. Risk factors include younger age, male sex, postoperative hematoma formation, diabetes, and revision surgery.[78,79] Although many methods have been used, no single intervention has been shown to reduce infection rates. Recent interest in addition of hydrogen peroxide and benzoyl peroxide to standard skin preparation shows promise in reducing colonization of *C acnes*, but reduction of infection rates remains to be seen.[80] Defining a prosthetic joint infection remains difficult. Recently, a committee gathered to define infection based on multiple weighted observations. Definite prosthetic shoulder infection is defined as meeting one of the following criteria: sinus tract from skin to the prosthesis, gross intra-articular pus, or two positive cultures with phenotypically identical virulent organisms.[81] If none of these criteria are met, differentially weighted minor criteria are used to define infection. When a prosthetic shoulder infection is identified, revision surgery with explantation of the device and intravenous antibiotics is the treatment of choice. The choice of revision as single stage or two stage is up to the treating surgeon. Both options have been shown to be viable.[82,83] When performing single-stage revision, the chapter authors recommend two separate surgical sets of instruments. After removal of the infected implant, thorough irrigation and débridement of all soft tissues should be performed in a stepwise fashion. The chapter authors recommend redraping the surgical field, removal of contaminated instruments, changing surgical attire, and use of fresh instruments for reimplantation. If two-stage revision is performed, the same débridement is performed with implantation of antibiotic-loaded polymethylmethacrylate spacer followed by 6 weeks of targeted intravenous antibiotics before reimplantation.

Neural injury after TSA is a rare but potentially devastating complication. The nerve at greatest risk is the axillary nerve, but any branch of the brachial plexus may be affected.[62,63,84] Most nerve injuries resolve with observation. Patients with a history of prior open shoulder surgery and those with less than 10° of passive external rotation are at greatest risk. Positioning of the arm at extremes of motion should be minimized. Allowing the arm to return to a neutral position frequently during the procedure may reduce neurologic injury.[85]

The shoulder surgeon should continuously examine his or her procedural steps and technique to minimize complications. This begins with initial evaluation of the patient, imaging, and proper surgical planning. Meticulous sterile technique, stepwise and tailored soft-tissue releases, and proper implant placement can help minimize shoulder arthroplasty complications.

Summary

Primary shoulder arthroplasty yields marked improvements for patients—measured in pain relief, improved motion, satisfaction, and patient outcomes. Improved patient outcomes are reported for reconstruction due to arthritis, rotator cuff deficiency, and fracture. Careful attention to preoperative planning and patient selection may improve overall results, especially when coupled with proper surgical procedures and instrumentation. Proper selection and surgical technique also reduce the incidence of serious complications, which are reported in the 1% to 3% range for primary shoulder arthroplasty. Prompt recognition and treatment of complications may reduce the impact of these events.

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