Review Article

Reverse Shoulder Arthroplasty for the Management of Proximal Humerus Fractures

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Abstract

The use of reverse shoulder arthroplasty is becoming increasingly popular for the treatment of complex three- and four-part proximal humerus fractures in the elderly compared with the often unpredictable and poor outcomes provided by open reduction and internal fixation and by hemiarthroplasty. Inferior results with plate osteosynthesis are often a result of complications of humeral head osteonecrosis, loss of fixation, and screw penetration through the humeral head, whereas major concerns with hemiarthroplasty are tuberosity resorption, malunion, and nonunion resulting in pseudoparalysis. Comparative studies support the use of reverse shoulder arthroplasty in elderly patients with complex proximal humerus fractures because the functional outcomes and relief of pain are reliably improved. Repair and union of the greater tuberosity fragment during reverse shoulder arthroplasty demonstrates improved external rotation, clinical outcomes, and patient satisfaction compared with outcomes after tuberosity resection, nonunion, or resorption. Satisfactory results can be obtained with careful preoperative planning and attention to technical details.

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Proximal humerus fractures, the third most common fracture type, account for nearly 5% of all fractures and are increasing in frequency with an aging population. Although three- and four-part fractures and fracture-dislocations account for <5% of all proximal humerus fractures, elderly patients are more prone to sustaining complex fracture patterns compared with younger populations.[1-3]

Fragility fractures of the proximal humerus are often highly comminuted and displaced and have poor bone quality, making them difficult to treat with open reduction and internal fixation (ORIF) or hemiarthroplasty. Concerns regarding plate osteosynthesis include humeral head osteonecrosis, loss of fixation, and screw penetration through the humeral head. Hemiarthroplasty for fracture, as introduced by Neer, offers a good solution for irreparable fractures, providing good pain relief; however, results may also include unpredictable functional outcomes.[4] Hemiarthroplasty outcomes are often bimodal, divided between excellent and poor outcomes, with the main determinant being the healing of the tuberosities.[5] With satisfactory tuberosity healing, patients often have good range of motion and excellent clinical outcomes. However, if there is tuberosity resorption, nonunion, or malunion, inadequate functional outcomes are common.[6] With this uncertainty in outcome after hemiarthroplasty, reverse shoulder arthroplasty (RSA) has been advocated for complex fractures because more consistent and predictable results are often achieved.[4] In both hemiarthroplasty and RSA, healing of the greater tuberosity leads to superior clinical outcomes; however, tuberosity healing is not a prerequisite for a good outcome after RSA.[4,7,8]

Management Options for Three- and Four-part Fractures

Complex proximal humerus fractures can be challenging to manage. Many patients benefit from surgery, whereas others are successfully managed nonsurgically, especially elderly patients with valgus impacted proximal humerus fractures. Nevertheless, other than this unique subgroup of patients, surgical intervention is most often recommended in medically fit and active elderly patients. The mainstays of surgical management include plate osteosynthesis, hemiarthroplasty, and RSA.

Plate Osteosynthesis and Hemiarthroplasty

With the advent of locking screw technology, the indications for plate osteosynthesis have expanded to include more comminuted and osteoporotic fractures. Open reduction and plate fixation is an excellent choice for significantly displaced two-part fractures, as well as for three- and four-part fractures without significant comminution or those occurring in younger adults. Risks of plate osteosynthesis include loss of fixation, screw head penetration into the joint, fracture collapse into varus, plate impingement, and osteonecrosis.[9]

Prior to the development of locking screw technology, hemiarthroplasty was the preferred mode of treatment of complex proximal humerus fractures. However, hemiarthroplasty is a technically challenging surgical procedure and may lead to poor results despite the best surgical efforts.[4] A functioning rotator cuff with anatomic tuberosity union is essential for a satisfactory outcome. Boileau et al[6] noted a 50% incidence of tuberosity malposition, with average forward flexion of 101° and external rotation of 18°. Other authors confirmed similar poor forward flexion (ie, a mean of 105.7°) after hemiarthroplasty in a systematic review of 81 proximal humeral fractures.[10] A randomized study comparing nonsurgical management with hemiarthroplasty for four-part fractures showed no notable difference in outcome.[11] These results underscore the high rate of poor outcomes and the importance of proper patient selection when hemiarthroplasty is considered.

In comparison with hemiarthroplasty, fixed-angle plate osteosynthesis has shown better functional outcomes and greater patient satisfaction in nonrandomized comparison studies.[12] Solberg et al[12] found higher Constant scores in the ORIF group at 3-year follow-up; however, patients with four-part fractures and those with varus angulation did worse than did patients with three-part fractures. Despite better outcomes, higher complication rates were found in the ORIF group, including osteonecrosis and screw-head cutout. When ORIF is performed on unstable varus fracture patterns in osteoporotic bone, a cortical strut graft may be helpful to support a deficient medial calcar.[13]

Reverse Shoulder Arthroplasty

Although RSA was originally developed for the treatment of rotator cuff tear arthropathy, the indications for its use have expanded over the past few years to include rotator cuff deficiency, irreparable rotator cuff tears, acute fractures, fracture sequelae such as malunion or nonunion, chronic dislocations, and revision arthroplasty and other salvage situations. The nonanatomic design principles of RSA make it a universal salvage option for a myriad of complex shoulder injuries and disorders in elderly patients. The function of the reverse prosthesis is based on the traditional Grammont principles of creating a semiconstrained prosthesis with a fixed fulcrum by which the deltoid elevates the arm without a functional rotator cuff.[14] By medializing the center of rotation, the deltoid is effectively lengthened and its moment arm is increased. These biomechanical changes reduce the forces required to abduct the arm, thus improving shoulder motion in the setting of a dysfunctional rotator cuff.[15] Implants with a lateralized glenosphere center of rotation were developed to decrease scapular notching and improve external rotation.[16] A biomechanical study showed that glenosphere lateralization improved joint stability but had no influence on external rotation and that it notably increased the deltoid force required for abduction.[17]

Patient Selection and Evaluation

RSA for complex three- and four-part proximal humerus fractures should be reserved for patients aged >70 years (Figure 1). Relative indications for RSA for fracture include the risk factors for inferior functional results from plate osteosynthesis or hemiarthroplasty (ie, irreparable fracture, high likelihood of humeral head osteonecrosis, poor tuberosity bone quality with osteoporosis and/or comminution, preexisting chronic rotator cuff tear and/or arthritis). Absolute contraindications for RSA include permanent axillary nerve dysfunction, global deltoid muscle

Figure 1

A B C

Reverse shoulder arthroplasty for fracture-dislocation. An independent, community-ambulating 84-year-old woman fell from a standing height and sustained a complex fracture-dislocation of the shoulder. **A,** AP radiograph demonstrating a three-part fracture-dislocation with tuberosity comminution. **B,** Immediate postoperative AP radiograph demonstrating a well-positioned reverse shoulder arthroplasty with a cemented stem and repaired greater and lesser tuberosities. **C,** AP radiograph at 7 months demonstrating an anatomically united greater tuberosity fragment without evidence of scapular notching or prosthetic loosening.

dysfunction, and global brachial plexopathy. However, if the brachial plexus injury is limited to the lower nerve roots with sparing of axillary nerve function, RSA may still be feasible. Partial deltoid dysfunction is a relative contraindication, but RSA may still provide reasonable results.[18] Relative contraindications also include an acromion or scapular spine fracture that may displace with deltoid tensioning, or a glenoid fracture or deficiency that precludes stable baseplate fixation. Arthroplasty should also be used with extreme caution in the setting of an open fracture because of an increased risk of infection. Furthermore, the inability to comply with postoperative restrictions and rehabilitation and significant medical comorbidities are relative contraindications for RSA. Implant longevity remains a concern, and few successful salvage options are available if the arthroplasty fails; long-term outcomes beyond 10 years are not well defined.

History and Physical Examination

The initial evaluation should include a general health assessment, including functional demands, independence, ambulatory status, cognitive impairment or dementia, and a history of shoulder injuries and surgeries. Proximal humerus fractures in the elderly are often fragility fractures associated with osteoporosis; therefore, patients should be referred for work-up and management of this disease, but a preoperative diagnosis of osteoporosis is not required. CT is used to estimate the degree of osteopenia.[19] Seventy-eight percent of patients are under-referred by orthopaedic surgeons after sustaining a fragility fracture.[20]

In fractures for which RSA is indicated, a detailed physical examination must be performed to assess for neurologic injury because axillary and/or suprascapular nerve injuries are more common—58% and 48%, respectively. Careful assessment of deltoid function is essential and is performed by having the patient elevate the arm while the examiner palpates over the anterior third of the muscle. If a contraction is felt, the function of the muscle is considered satisfactory.[21] However, if an axillary nerve injury is suspected, electromyography should be obtained because intact deltoid muscle function and axillary nerve function are prerequisites for a well-functioning RSA.

Radiographic Imaging

A standard shoulder radiographic series, including AP, scapular-Y, and axillary views, allows for initial evaluation of the injury, fracture classification, and surgical templating. CT is routinely obtained to further evaluate fracture reparability, assess for rotator cuff fatty degeneration as described by Goutallier et al,[22] define the severity of tuberosity comminution and osteoporosis, and assess for associated fractures or deficiencies of the glenoid that may compromise baseplate fixation. If necessary, the operative and contralateral humerus may be measured radiographically to help template the lengthening of the operative shoulder.[23]

Authors' Preferred Surgical Technique

Regional anesthesia is administered preoperatively, and patients are placed in the beach-chair position with either light sedation or general anesthesia. Some surgeons prefer to avoid regional anesthesia because the paralytic effect of the nerve block may reduce deltoid tone, thus risking immediate postoperative dislocation, but in our experience, this has not occurred, and immediate stability is conferred by appropriate soft-tissue tensioning. For adequate exposure, the operative arm must be free to allow for full adduction and extension. A deltopectoral approach is our preferred approach because it does not violate the deltoid muscle and it limits risk to the axillary nerve; both structures are at increased risk with a deltoid-splitting anterosuperior approach, even though the anterosuperior approach may offer advantages of glenoid exposure, a preserved subscapularis in a nonfracture setting, and a low risk of postoperative instability.[24]

One centimeter of the proximal pectoralis major insertion may be released from the humerus for added exposure if necessary. The subdeltoid and subacromial bursal scarring is released bluntly. The clavipectoral fascia is opened along the muscular lateral border of the strap muscles, and the axillary nerve is palpated. At this point, the proximal humerus fracture can be identified and evaluated for irreparability and the need for RSA. Signs of fracture irreparability include (1) tuberosity comminution, (2) indiscernible fracture fragments, (3) soft bone that depresses under digital pressure, (4) egg-shell–like cortical bone, (5) humeral head devoid of soft-tissue attachment, and (6) significant fracture displacement and/or calcar comminution. The long head of the biceps tendon is unroofed from the intertubercle groove to assist in identifying the tuberosities that are freed and tagged with heavy nonabsorbable sutures. At the end of the procedure, the biceps is tenotomized if the patient is obese or is tenodesed to the adjacent soft tissue if there is a cosmetic concern. The humeral head fragment is excised and saved for autograft.

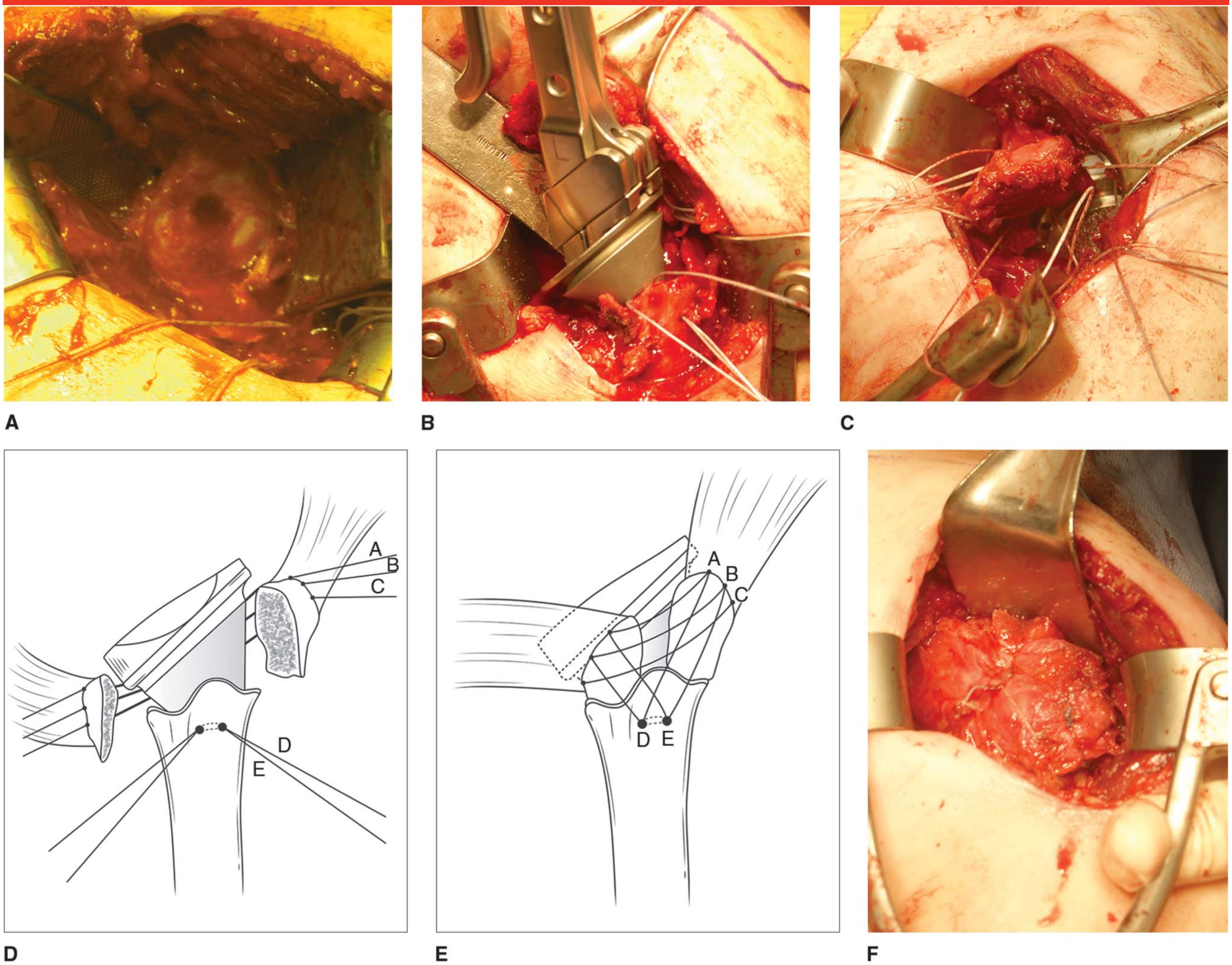
The humerus is prepared for arthroplasty with serial canal reaming until detection of mild cortical chatter that typically correlates with preoperative canal size templating. Often the proximal humerus does not require a neck osteotomy, given the fracture comminution. The choice of the humeral implant is surgeon dependent; some stems are designed for ingrowth or have areas for bone autograft, but no studies have demonstrated superiority of one stem over another. The height and version of the trial implant is judged by the intact humeral calcar, tuberosity fragment reduction, and stem version guide system.

The procedure then addresses glenoid preparation, and the humeral trial stem is removed to increase exposure to the glenoid. In the setting of a fracture, glenoid exposure is often excellent and unencumbered because the tuberosities are fractured off the proximal humerus. Glenoid preparation includes circumferential labrectomy with a focus on exposing the inferior glenoid rim and subperiosteally elevating 0.5 cm of tissue off the inferior glenoid neck to ensure proper baseplate positioning. The baseplate guide is aligned with the inferior glenoid rim in neutral to 10° inferior tilt, and the glenoid is drilled. The glenoid is reamed to a flat surface, usually through the subchondral bone inferiorly, but leaving the subchondral bone intact at and above the equator (Figure 2, A). The baseplate is impacted into the glenoid, and locking screws are inserted. The superior screw is aimed toward the coracoid base; the inferior screw is aimed toward the scapular body and down the lateral scapular border. The glenosphere size is chosen based on patient size, impingement-free motion, anatomy, and concern for implant stability; female patients and smaller patients typically receive a 36-mm size, and large men or patients with instability receive a 40-mm size. The chosen glenosphere is inserted onto the baseplate.

The trial humeral components are replaced; attention is paid to height relative to the intact calcar and stem version relative to the forearm near 20° of retroversion (Figure 2, B). The version of the stem may affect stability postoperatively, as demonstrated in biomechanical and finite element analysis studies.[25] If the calcar bone is missing, the height of the stem is judged by reducing the prosthesis and applying axial traction to judge the appropriate height of the implant. Additionally, anatomic landmarks such as the pectoralis insertion, which resides approximately 5.6 cm from the top of the fractured humeral head, may be used to assist in estimating the height of the stem.[26]

The prosthesis is reduced, and the greater tuberosity is anatomically positioned; tension and stability of the articulation are then assessed. The lesser tuberosity is repaired if it constitutes a large portion of bone or if the subscapularis is deemed necessary for prosthetic stability or function. The appropriate thickness and the retentive characteristics of the polyethylene liner are chosen based on the axial shuck test, lateral stability, lack of adduction deficit, and strap muscle tightness. Tensioning is at the discretion of the surgeon; the appropriate soft-tissue tension is

Figure 2



Surgical technique of reverse shoulder arthroplasty for fracture in the same patient shown in Figure 1. **A,** Intraoperative photograph demonstrating that reaming is slightly eccentric, with more bone removed on the inferior one third of the glenoid face down to cancellous bone, preserving the subchondral bone near the equator and superior portions of the glenoid face. **B,** Intraoperative photograph demonstrating humeral preparation and stem trialing focusing on the proper stem height relative to the calcar and version. **C,** Intraoperative photograph demonstrating tuberosity fixation performed after final stem cementation and polyethylene insertion and prosthetic reduction. The lesser tuberosity is shown with sutures before tying. The greater and lesser tuberosities have three horizontal cerclage sutures around the stem and two vertical fixation sutures. **D** and **E,** Illustrations demonstrating tuberosity suture repair similar to configurations used during hemiarthroplasty. Three horizontal cerclage sutures, marked A, B, and C, go around the stem neck; two vertical sutures for the greater tuberosity repair are marked D and E. **F,** Final intraoperative photograph demonstrating a lesser and greater tuberosity repair construct with autologous bone grafting with excellent stability of the fragments during arm elevation and rotation.

unknown, but it is critical for prosthetic stability. It is easy to overlengthen the arm in the setting of an acute fracture, given the significant soft-tissue disruption. Appropriate length and soft-tissue tension should be assessed after tuberosity fixation, ensuring that prosthetic stability is provided throughout a full range of motion. Soft tissues are appropriately tensioned when manual dislocation is difficult to achieve with axial and lateral forces.[27]

Tuberosity preparation includes mobilization with release of the anterior supraspinatus tendon to allow for distal-lateral reduction of the tuberosity to the humeral cortex; this is typically 1.5 cm distal to its original position because of the arm lengthening created by RSA. Tuberosity fixation is then performed with three nonabsorbable horizontal cerclage sutures around the stem and two vertical sutures placed through the anterolateral humeral cortex and greater tuberosity (Figure 2, C through E). In the fracture setting, we typically choose to fully cement the stem using a cement restrictor because of metaphyseal fracture bone loss and jeopardized stem fixation.

Once the stem is cemented, the appropriate polyethylene is inserted. Next, the greater tuberosity, and possibly the lesser tuberosity, is repaired and bone grafted with morcellized cancellous humeral head. The horizontal cerclage sutures are tied to compress the anatomically reduced tuberosity onto the ingrowth humeral stem. Bone graft is impacted into areas of void to enhance osseous healing. Because over-reduction of the greater tuberosity may occur inferiorly, the vertical sutures are tied only after the horizontal sutures have compressed the fragment to the prosthesis (Figure 2, F). Impingement-free range of motion and tuberosity fixation are then confirmed.

A deep drain is placed to minimize the risk of hematoma formation despite a lack of evidence for its use; the wound is then closed, and the arm is placed into a pillow abduction device sling. Postoperative rehabilitation includes pillow abduction device sling immobilization for 4 weeks, followed by passive- and active-assisted forward elevation in the plane of the scapula.

Prosthetic Design for Fracture

With the growing popularity of RSA for fracture, specific humeral stems are now designed to enhance the bony healing of tuberosities. Some stems have proximal ingrowth potential or have roughened or spiked metal to control fragments; other stems are coated with hydroxyapatite or have windows in the proximal stem to allow for extra bone grafting to enhance tuberosity consolidation. No comparative studies have been performed to demonstrate the superiority of these stems during RSA for fracture.

Commonly the humeral stem is fully cemented in the canal because proximal metaphyseal fixation is jeopardized. Stem radiolucent lines are a rare occurrence in cemented RSA, but resorption of tuberosities is common, presumably from stress shielding. A study of Grammont-style cemented stem RSAs with 9-year follow-up demonstrated that >50% of stems had tuberosity resorption and 12% had three or more zones (of seven zones total) with >2 mm of radiolucency.[28] Noncemented ingrowth stems appear to have improved resilience to developing radiolucency and may minimize tuberosity stress shielding; however, a noncemented stem should not be used if intraoperative rotational or axial fixation is poor.[29] The significance of these stem radiolucencies is of unknown clinical consequence.

Deltoid and Soft-tissue Tension

Proper tensioning of the soft tissues during RSA is imperative, not only to render a mechanical advantage for deltoid function, but also to provide stability through concavity compression of the semiconstrained articulation. Both axial tension and horizontal tension are important to consider. In the fracture setting, the soft-tissue integrity around the proximal humerus may be significantly compromised, and overlengthening is possible. Lengthening of 1.5 cm was originally described by Boileau et al[14] as promoting sufficient deltoid tension. More recent studies suggest that while greater deltoid lengthening may lead to improved forward flexion,[30] it may also be associated with the development of deltoid fatigue[31] or acromial stress fracture with poor outcome.[15] Therefore, tensioning of the reverse prosthesis is subjective and is considered a balance of risk and rewards with regard to stability and function.

Intraoperative soft-tissue tension may be assessed by several maneuvers: the axial shuck test, lateral instability, adduction deficit, and strap tightness in neutral extension. Tension may be adjusted by increasing the humerosocket polyethylene thickness, implanting the humeral stem proud or deep, changing the glenosphere diameter or its position if an eccentric glenosphere is available, and lateralizing the glenosphere to improve the horizontal compressive force on the articulation.[32] The shuck test, performed with axial traction on the adducted humerus, assesses for an optimal 1 to 2 mm of articulation gapping. The lateral instability test is performed by placing one finger on the humeral calcar, applying a lateral dislocation force, and checking for ease of dislocation or subluxation.[27] Adduction deficit is checked with gravity adduction; a deficit is created if the humerus is overlengthened or if the baseplate is too superior, thus allowing impingement of the humerosocket on the inferior glenoid.[33] The tightness of the strap muscles in neutral extension ensures that these muscles contribute to joint compression and that they are not so tight as to create an extension deficit. The axillary nerve should be palpated to ensure that it is not too taut. Establishing the correct tension is subjective and involves a balance between providing stability and active motion while not overlengthening to the point of potentially causing neurapraxia, acromial fracture, or deltoid dysfunction.

Greater Tuberosity Repair

Controversy exists regarding the importance of greater tuberosity fragment fixation during RSA. Early studies on the treatment of proximal humerus fractures with RSA described greater tuberosity fragment excision with good results, whereas other studies have found improved

Table 1

Outcomes from Reverse Shoulder Arthroplasty for Fracture[a]

Study	No. of Patients	Follow-up (months)	Active Forward Elevation (degrees)	Active External Rotation (degrees)	Constant Score	Complications	Greater Tuberosity Repair (Yes/No)
Cazeneuve et al[34]	30	78	—	—	53	13% major, 60% scapular notching	No
Klein et al[8]	20	33	122	25	67	15%	No
Gallinet et al[4]	16	12	98	9	53	19%	No
Bufquin et al[7]	40	22	97	8	44	28%	Yes
Sirveaux et al[35]	20	79	107	10	55	—	Yes
Lenarz et al[36]	30	23	138	27	—	3%	Yes
Gallinet et al[37]	27	24	117	15	60	8% tuberosity nonunion, 70% notching	Yes

[a] Data are presented as means.

results with tuberosity repair[4,7,8,34-37] (Table 1).

Comparing the outcomes of multiple studies demonstrates trends toward improved external rotation with a repaired and healed greater tuberosity fragment. Whereas RSA does not require a functional posterosuperior rotator cuff for overhead elevation, repairing the greater tuberosity and restoring the function of the infraspinatus and teres minor may improve external rotation strength and function.[7] In a study by Gallinet et al,[37] patients with anatomic tuberosity healing were compared with a group of patients with malunion, nonunion, or excision of the greater tuberosity. The group with an anatomically healed greater tuberosity demonstrated significantly better external rotation (49° versus 10°), DASH scores (30 versus 40), and Constant scores (65 versus 50). Interestingly, malunion of the greater tuberosity was not the result of secondary displacement but rather of intraoperative malreduction.

Because of the importance of anatomic tuberosity healing, numerous strategies and techniques have been described to repair the tuberosities, with most using numerous vertical and horizontal sutures (Figure 2, D and E) or wires. Bone autograft from the resected humeral head may be morcellized and packed into areas of void around and beneath the tuberosity, or it may be used as a structural graft wrapping around the proximal stem, providing improved surface area for tuberosity healing. Radiographic evaluation of anatomic greater tuberosity healing (Figure 3) is defined as AP view visualization of the greater tuberosity in neutral rotation with osseous union with the lateral humeral shaft.[37]

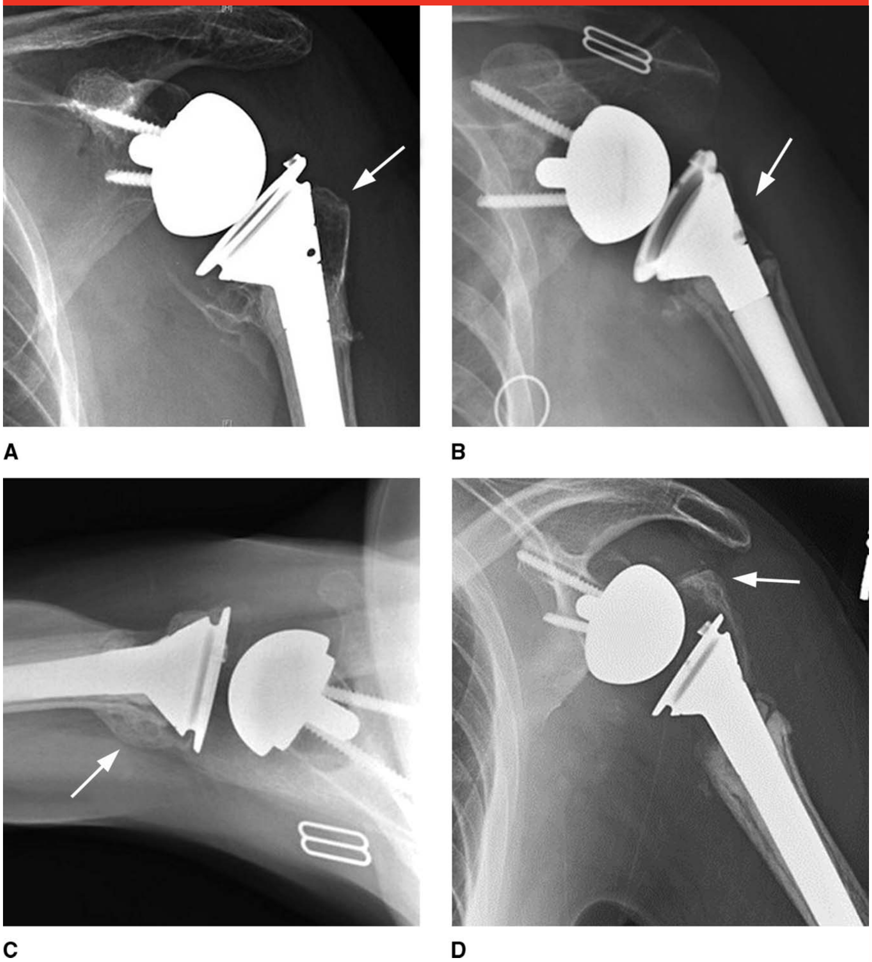
Lesser Tuberosity/ Subscapularis Repair

Limited data exist on the effects of lesser tuberosity or subscapularis repair on the outcomes of RSA for fracture. A deficient subscapularis predisposing the prosthesis to anterior instability is a concern. Additionally, there is concern that repairing the subscapularis effectively weakens the remaining external rotators by increasing the overall internal rotation forces. Controversy regarding whether to repair the subscapularis remains unresolved. One retrospective study found that a subscapularis repair does not affect RSA stability.[38] Another case series found that a repaired subscapularis decreased the risk of instability.[39] In our practice, we do not routinely repair the lesser tuberosity or subscapularis when performing RSA in the fracture setting unless there is concern for significant bone loss from fragment excision or for intraoperative anterior instability.

Impingement-free Range of Motion

Component positioning and prosthetic design are important factors that affect impingement-free range of motion.[40] Simulation studies measuring abduction, forward elevation, and internal and external rotation after altering the glenosphere position in both the coronal and sagittal planes have demonstrated that the optimal glenosphere position that minimizes impingement was inferiorly positioned, inferiorly tilted, and lateralized in all degrees of

Figure 3



Radiographic assessment of greater tuberosity healing. Radiographic osseous union of the greater tuberosity is important to assess after reverse shoulder arthroplasty for fracture because anatomic tuberosity union improves function. Assessment has been adapted from evaluation of the tuberosity position after hemiarthroplasty.[3] **A,** AP radiograph at 14-month follow-up demonstrating anatomic greater tuberosity healing. Consolidation of the greater tuberosity is defined as visible bone (arrow) lateral to the humeral stem with the arm in neutral rotation, with bridging union to the lateral cortex of the humerus.[34] **B,** AP radiograph at 6-month follow-up demonstrating malunion of the greater tuberosity, defined by the lack of visible tuberosity (arrow) lateral to the stem on neutral rotation. **C,** Axial view demonstrating a malunited tuberosity (arrow). **D,** AP radiograph at 6-month follow-up demonstrating nonunion of the greater tuberosity, defined by a lack of bridging bone or progressive vertical or horizontal displacement of the tuberosity (arrow). Tuberosity dissolution may also occur and may be confused with malunion; CT often demonstrates a lack of tuberosity bone, indicating complete resorption.

scapular angles measured.[41,42] In addition, a more varus humeral neck shaft angle (ie, 130° versus 150°) corresponds with fewer adduction deficits and less scapular notching.[33]

Version of the humeral stem also affects rotation of the shoulder. The humerosocket is usually positioned between 0° and 20° of retroversion. With less humeral retroversion, there is a loss of external rotation before impingement.[15] Therefore, patients with a functioning posterior rotator cuff may benefit from increased stem retroversion to allow for increased external rotation before impingement. In one study, neutral version was shown to correlate with better functional outcomes and fewer glenoid complications.[43]

Scapular Notching

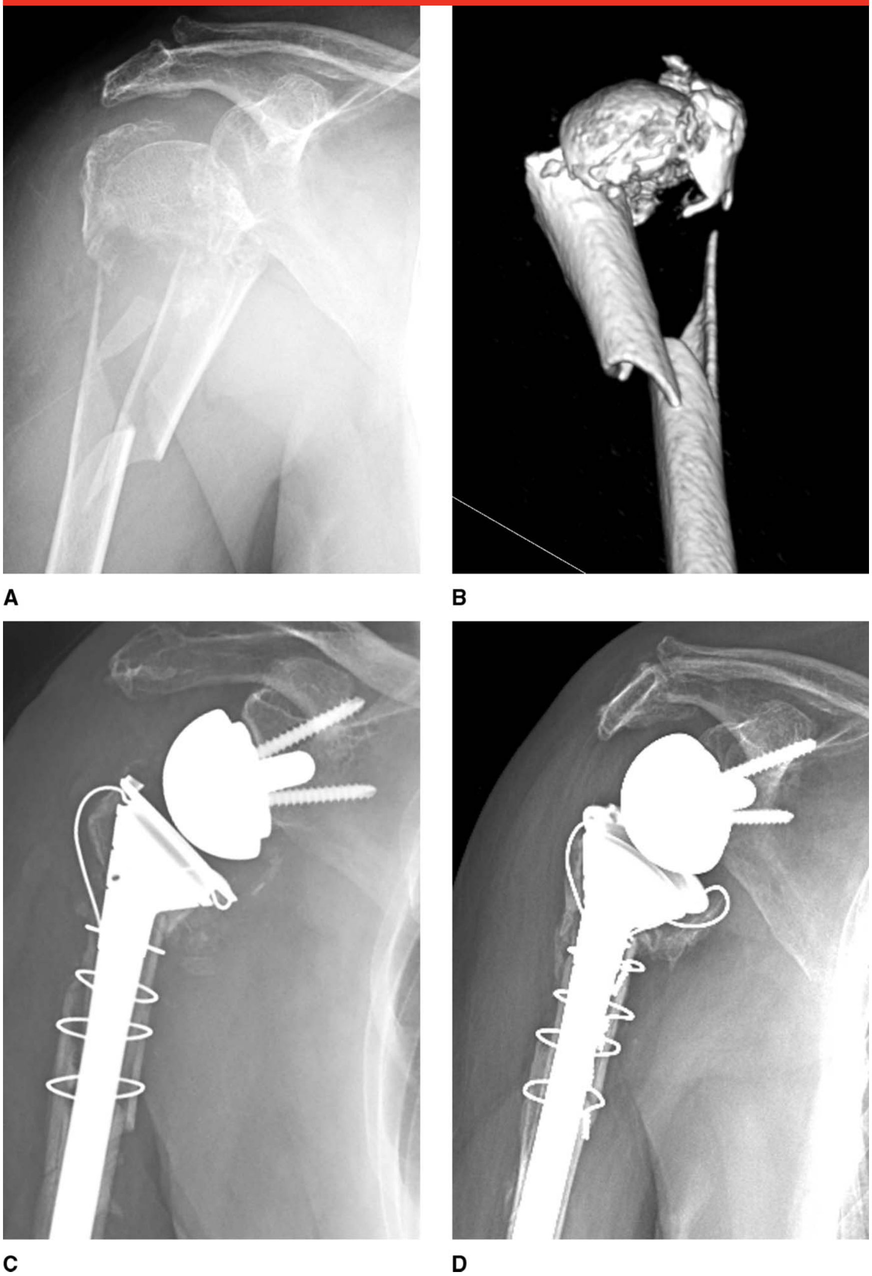
Scapular notching is a radiographic finding after RSA and is likely a consequence of mechanical impaction and a biologic reaction to abrasion or polyethylene wear debris. Notching likely occurs with contact between the scapular neck and the polyethylene during adduction. Notching may occur within the first few months after surgery or develop years afterward. Although reports vary, the incidence may be as high as 44% to 96% with the Grammont-style prosthesis.[40,44,45] Not only can notching jeopardize baseplate fixation,[46] but it is also associated with poor patient outcomes and is an independent risk factor for failure.[40]

Predictors of notching include superior positioning of the glenosphere, medialization of the center of rotation, and a high body mass index.[40] Lateralized glenospheres have been developed that have lower rates of scapular notching,[16] but they exhibit increased baseplate-bone interface shear forces. A biologic solution to these troubling shear forces involves lateralizing the baseplate with the use of a structural autograft. A prospective study with this structural autograft for baseplate lateralization demonstrated 98% incorporation of the graft with the glenoid and was associated with only 19% notching.[47] However, a randomized controlled trial demonstrated no difference in notching or clinical outcome using this bony offset technique compared with the standard technique without autograft.[48]

Clinical Outcomes

The clinical outcome after RSA for fracture is good; most studies

Figure 4



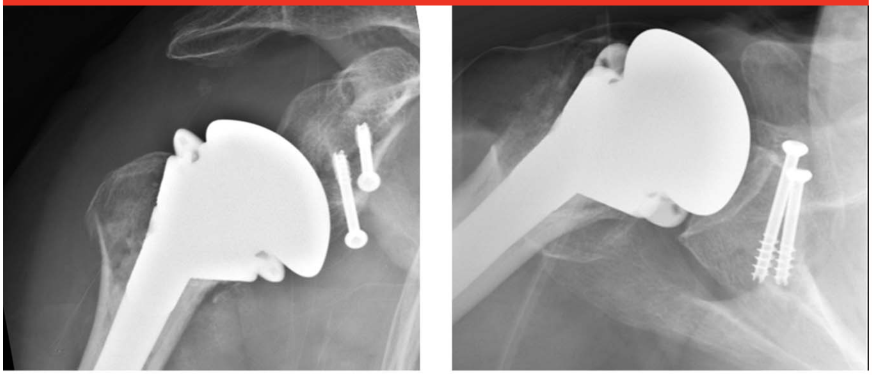
A, AP radiograph demonstrating a complex proximal humerus fracture sustained by a 72-year-old woman. **B,** Three-dimensional CT reconstruction demonstrating comminuted tuberosities and a significantly displaced proximal humerus fracture with risk for humeral head osteonecrosis. **C,** Immediate postoperative AP radiograph demonstrating a reverse shoulder arthroplasty performed with distal cementation of a long stem prosthesis and cerclage fixation of the proximal shaft and of the tuberosity fracture fragments. **D,** AP radiograph at 9 months postoperative demonstrating active forward elevation of 110° with 10° of external rotation, with minimal shoulder pain but evidence of an acromial base fracture with caudal angulation.

demonstrate forward elevation of approximately 95° to 145°, external rotation of approximately 0° to 25°, and Constant scores of approximately 50 to 65 (Table 1). In a series of 30 patients who underwent RSA for three- and four-part fractures, 2-year follow-up results showed an average forward flexion of 139°, external rotation of 27°, and an American Shoulder and Elbow Surgeons score of 78.[36] In a similar retrospective study of 27 patients at nearly 2-year follow-up, an average forward flexion of 112°, abduction of 97°, external rotation of 12.7°, and a Constant score of 55 were reported.[49] In another series of 41 patients who underwent RSA for fracture, 2-year follow-up results demonstrated improved forward elevation of 104° versus 94° and external rotation of 33° versus 20° in patients aged <75 years compared with their older cohorts. Tuberosity healing occurred in only 41%, and tuberosity nonunion or malunion resulted in diminished external rotation.[4]

Randomized studies comparing hemiarthroplasty and RSA for fracture are lacking, but comparative studies demonstrate equivalency or favorable outcomes for RSA.[4,50,51] Gallinet et al[4] retrospectively compared 17 patients who underwent hemiarthroplasty with 16 patients who underwent RSA. Short-term results revealed increased forward flexion, abduction, and Constant scores in the RSA group, but the hemiarthroplasty group had better external rotation of 13.5° compared with 9° for patients who had undergone RSA.

Mid- and long-term studies of RSA for rotator cuff deficiency demonstrate a 94% implant survivorship, with maintained range of motion and pain control at 5 years.[52] A 10-year follow-up study of RSA demonstrated a survival rate of 91% of the prosthesis, with most revisions occurring within the first 3 years. However, there was an ominous decrement in function at 6 years, with only 60% of patients maintaining a Constant score >30.[53] A similar decrement in function is observed in RSA for fracture with a Grammont design and may be related to progression of notching and baseplate loosening or to deltoid fatigue, or it may be a consequence of natural decline with aging.[34]

Figure 5



A **B**

Reverse convertible stem hemiarthroplasty for a proximal humerus fracture. A 74-year-old woman sustained a four-part proximal humerus fracture and a comminuted glenoid fracture that precluded stable reverse shoulder arthroplasty (RSA) baseplate fixation. Postoperative AP **(A)** and axillary **(B)** radiographs following hemiarthroplasty with a convertible RSA stem and open reduction and internal fixation of the glenoid and tuberosities. This hemiarthroplasty, performed with a stem designed for RSA, allows for an easier future conversion to an RSA if the tuberosities fail to heal, if instability develops in the shoulder, or if the shoulder is pseudoparalytic.

Complications

Complication rates of RSA for fracture vary among studies and range from 5% to 40%.[54] Complications include scapular notching, glenoid loosening, instability, acromial fracture (Figure 4), deltoid fatigue, nerve palsy from lengthening tension or iatrogenic injury, pain syndromes, periprosthetic fracture of the humerus or glenoid, and infection. Cheung et al[44] reported that management of these complications is difficult. Intraoperative or unrecognized glenoid fracture may occur, especially in the setting of trauma and osteoporosis; bailout options such as hemiarthroplasty should be considered if stable baseplate fixation cannot be safely achieved (Figure 5). Cazeneuve and Cristofari[34] reported that the most common complications during RSA for fracture were dislocation (4 of 36 fractures), reflex sympathetic dystrophy (2 of 36 fractures), and infection (1 of 36 fractures). Revision rates of RSA for fracture are 5% to 15%, even among highly skilled surgeons. The most common reason for revision is instability, although glenoid complications and wound infection also significantly contribute to revision rates.

Summary

RSA has become a successful option for managing complex proximal humerus fractures in the elderly. RSA has the advantage of providing reliable outcomes compared with the unpredictable results of hemiarthroplasty. Satisfactory results may be obtained with careful preoperative planning and attention to technical details. A focus on greater tuberosity fixation during RSA has resulted in improved external rotation and clinical success. However, unlike hemiarthroplasty, tuberosity healing is not a prerequisite for a good clinical outcome. With encouraging short- and mid-term results and a low complication profile compared with hemiarthroplasty, RSA for fracture will likely become a pillar in the treatment algorithm of complex proximal humerus fractures. However, longer-term follow-up is imperative before widespread use of RSA can be recommended.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 11 and 20 are level I studies. Reference 30 is a level II study. References 4, 23, 31, 37, 38, 45, and 49-51 are level III studies. References 5-10, 12-19, 22, 24-29, 32-34, 36, 39-44, 46, 47, and 52-54 are level IV studies.

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