Management of proximal humerus fractures utilizing reverse total shoulder arthroplasty

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Abstract The increased incidence of proximal humerus fractures has resulted in a thoughtful evolution of treatment options in order to optimize clinical outcomes. Complex three- and four-part fractures present a treatment challenge, particularly in elderly patients with significant medial comorbidities and poor bone quality. While open reduction and internal fixation is a reasonable surgical option in some patients with acceptable bone quality and simple fracture patterns that are not susceptible to avascular necrosis, shoulder hemiarthroplasty is a well-established procedure for many elderly patients (i.e., >70 years). Historically, hemiarthroplasty has provided reliable pain relief, but outcomes with regard to function, motion, and strength have varied.

Ultimately, successful outcomes are dependent upon tuberosity healing, since an intact rotator cuff is required to restore function. With the advent of reverse total shoulder arthroplasty (RTSA) and increased familiarity with the surgical technique, successful outcomes have been achieved in older patients with poor potential for tuberosity healing. In this review, we discuss the recent role of RTSA in the setting of proximal humerus fractures, including surgical indications, preferred operative technique, and recent literature that supports its use.

Keywords Reverse total shoulder arthroplasty · Proximal humerus fracture · Fragility fracture · Fracture sequelae

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Introduction

A recent epidemiological study of proximal humerus fractures estimated an annual incidence of up to 105 fractures per 100,000 patients [1]. Current trends suggest an expected three-fold increase in the number of proximal humerus fractures by 2030 [2]. Many patients who sustain proximal humerus fractures are elderly, since 70 % of all three- and four-part fractures are observed in patients older than 60 years. Additionally, the highest age-specific incidence for these fractures was noted in women between 80 and 89 years [3]. These observations suggest that many of these fractures may present a particularly difficult treatment challenge, since the quality of bone may be compromised in this older population. Ultimately, osteoporosis is thought to play an important role in fractures observed in this age group, given recent studies that estimate that proximal humerus fractures currently rank third in fragility fractures [3].

Despite the advent of locking plate technology, complications such as loss of fracture reduction and screw penetration occur at high rates (21 %–43 %) in older patients with three- or four-part fractures [4, 5]. Avascular necrosis is

also observed in complex fracture patterns, since the vascular supply to the humeral head may be compromised by the initial injury or extensive surgical dissection at the time of fracture fixation [6]. These complications have resulted in inconsistent clinical results with regard to range of motion, pain relief, and overall function following open reduction and internal fixation (ORIF) [7, 8].

Given the operative challenges and increased complications associated with ORIF in the setting of complex proximal humerus fractures, some surgeons have favored shoulder arthroplasty in the older population. In 1970, a landmark article by Charles Neer concluded that complex four-part proximal humerus fractures should be treated with humeral head replacement to provide optimal clinical outcomes [9]. While this study has served as a long-standing reference for surgical decision making over the last several decades, follow-up studies have demonstrated unpredictable results. Overall, shoulder hemiarthroplasty yields dependable pain relief postoperatively; however, many patients demonstrate poor functional results with regard to range of motion and function [10–16]. Functional outcomes are largely dependent upon appropriate position, fixation, and union of the tuberosities [11]. A study by Loebenberg et al. demonstrated that active range of motion was largely influenced by the placement of the greater tuberosity relative to the superior aspect of the prosthetic humeral head. The authors noted that optimal placement of the tuberosity was 10–16 mm distal to the superior margin of the prosthesis, since this position resulted in significantly improved active forward elevation and external/internal rotation [17]. The role of rotator cuff integrity in the setting of shoulder hemiarthroplasty was recently highlighted by Greiner et al. The authors noted a significant correlation between tuberosity malposition and fatty infiltration of the supraspinatus/infraspinatus muscles (greater tuberosity malposition) and the subscapularis muscle (lesser tuberosity malposition) [18]. This resulted in lower outcome scores for these patients, thus demonstrating the important role of rotator cuff musculature in postoperative function.

The role of reverse total shoulder arthroplasty in the setting of fractures

The reverse total shoulder prosthesis was initially designed to manage glenohumeral arthritis in the setting of rotator cuff insufficiency (i.e., rotator cuff arthropathy). An improved prosthesis introduced by Paul Grammont utilized an inverse component design to create a semiconstrained prosthesis with a fixed fulcrum at the glenohumeral joint. With improved understanding of the imbalance of muscular forces within the rotator cuff deficient shoulder, this design increased the deltoid moment arm by medializing the center

of rotation, relative to the glenoid neck, and moving the insertion site of the deltoid in a distal direction [19]. Ultimately, the longer deltoid lever arm afforded greater recruitment of deltoid fibers to facilitate humeral elevation and abduction in patients who did not have a functional rotator cuff [19].

Increased utilization and familiarity with reverse total shoulder arthroplasty (RTSA) has resulted in expanded surgical indications. The current role of RTSA for the treatment of acute proximal humerus fractures and fracture sequelae (i.e., nonunion and malunion) continues to develop; however, recent studies clearly support its use in fractures with specific characteristics. RTSA offers obvious functional benefits over traditional hemiarthroplasty in the setting of acute three-part and four-part proximal humerus fractures and fracture/dislocations that demonstrate poor potential for tuberosity healing (i.e., comminuted tuberosities, osteoporotic bone). Given the implant design, tuberosity nonunion or malunion is less debilitating, since the patient is able to retain active elevation with a functional deltoid muscle. Clearly, secure tuberosity fixation is attempted in each case, since successful union can result in preservation of external rotation [20].

Patient selection and preoperative evaluation

Appropriate patient selection is paramount to obtaining successful postoperative outcomes. Patient age is an important consideration, since implant longevity remains an obvious concern. In general, primary RTSA should be reserved for elderly patients (age greater than 70 years). Various studies have identified risk factors for inferior functional outcomes following shoulder hemiarthroplasty, including poor tuberosity status (i.e., comminuted, osteoporotic), preexisting rotator cuff pathology, inability to comply with prolonged immobilization and specific rehabilitation, and significant associated comorbidities [11, 16, 21, 22].

A thorough history and a physical examination are necessary to determine important patient elements that may influence postoperative function. Careful assessment of the neurovascular status is important in each case, since suprascapular and/or axillary nerve injuries have been reported in up to 82 % of patients with severely displaced fractures [23]. Electromyography can be utilized to confirm neurological status if the physical examination is unclear. The importance of neurological assessment cannot be overstated, since RTSA in the setting of a dysfunctional deltoid could result in poor postoperative function, as well as prosthetic instability.

Initial radiographic assessment should include a routine trauma series of the involved shoulder, comprising AP, scapular-Y, and axillary views. Further investigation of fracture pattern/displacement, tuberosity status, including degree of comminution, and the presence of fatty infiltration of the rotator cuff is facilitated with computerized

tomography (CT). CT scan can also aid in the analysis of glenoid bone stock and quality, which proves useful for preoperative determination of glenoid base placement (Fig. 1a–f).

Surgical technique

The surgical principles for RTSA performed in the setting of proximal humerus fractures are similar in detail to those for

RTSA used for operative management of rotator cuff arthropathy. However, special emphasis is placed on tuberosity reconstruction around the humeral component to optimize surgical outcome. This focus follows principles similar to those applied during shoulder hemiarthroplasty.

The patient is appropriately anesthetized and placed in the Semi-Fowlers position, with the arm draped free and lateralized enough to allow full extension in adduction throughout the case. A standard deltopectoral approach is

Fig. 1 **a** CT scan of a 78-year-old woman who sustained a four-part proximal humerus fracture-dislocation (anterior). The axial view demonstrates an associated fracture of the anterior-inferior glenoid. **b, c, d** Sagittal (panel b), oblique sagittal (panel c), and oblique coronal (panel d) views demonstrate the size of the glenoid fracture. **e** A Biomet Comprehensive (Warsaw, IN) mini-baseplate (25 mm) was used, which allowed stable osseous fixation within the intact glenoid. **f** Final postoperative radiographs

used in order to gain access to the fracture and isolate the greater and lesser tuberosities. Once adequate exposure is obtained, each tuberosity is tagged at the bone tendon interface with heavy nonabsorbable sutures that are utilized in the final reconstruction. The humeral head fragment is carefully removed, and the humeral shaft is reamed to a tight fit. Hand reaming is typically performed to prevent iatrogenic fracture or fracture propagation.

Following humeral preparation, retractors are appropriately placed to facilitate exposure of the entire glenoid. The glenoid is reamed, and the implant-specific baseplate is impacted into place and secured with screw fixation. A trial glenosphere is subsequently inserted, and attention is again directed to the humeral shaft, which is finally prepared for insertion of the humeral stem component. Depending upon the system, the humeral stem may be press fit or cemented. However, prior to placement of the stem, two drill holes are created posterolaterally and posteromedially to the bicipital groove to insert two heavy nonabsorbable sutures to aid in longitudinal fixation of the tuberosities at a later stage in the case.

The humeral component is placed in 20° – 30° of retroversion, and trial reduction is performed utilizing an appropriately sized humeral tray trial. Both range of motion and deltoid tension are carefully assessed, and once the appropriate combination of glenosphere and humeral tray components are chosen, the trial implants are removed and the final glenosphere is impacted into place. The humeral stem is subsequently inserted (press fit or cemented).

At this point, attention is directed toward careful reconstruction of the greater and lesser tuberosities. The transverse sutures initially placed within the tuberosities are placed around the medial aspect of the humerus and passed through the other tuberosity in an “inside-out” fashion at the muscle–tendon junction. A minimum of two to four transverse sutures are placed. Next, the final humeral tray component is impacted, and the joint is reduced. The longitudinal sutures previously placed through the shaft are subsequently passed through the superior portion of the greater and lesser tuberosities. The transverse sutures are tied so as to compress the tuberosities against the humeral shaft and approximate them to each other. Next, the longitudinal sutures are tied to secure the final reconstruction. (Fig. 2a–d) The shoulder is passively abducted and rotated to ensure that the reconstruction is stable. Final wound closure is performed over drains if necessary.

Postoperative rehabilitation

Patients are immobilized in a shoulder sling with an abduction pillow for a minimum of 6 weeks to facilitate union of the greater and lesser tuberosities. During this period, active distal range of motion (elbow, wrist, and hand) is encouraged, and gentle passive range of motion to 120° in the

Fig. 2 a, b Radiographs of a 78-year-old woman who sustained a four-part proximal humerus fracture following a traumatic fall. c Longitudinal and transverse sutures are placed through the tuberosities for eventual repair. d Final tuberosity reconstruction

plane of the scapula is allowed. Gentle pendulum exercises are initiated to facilitate shoulder range of motion. If follow-up radiographs reveal adequate tuberosity healing with no evidence of migration, active range of motion is initiated at approximately 6 weeks postoperatively.

Clinical outcomes

Acute proximal humerus fractures

Recent studies utilizing RTSA as primary treatment for complex proximal humerus fractures have provided early data to help guide surgical decision making. A study by

Bufquin et al. prospectively evaluated 41 consecutive elderly patients (mean age, 78 years) that sustained three- and four- part proximal humerus fractures between 2000 and 2005 [20]. These patients underwent acute management utilizing the Delta prosthesis (Depuy, Saint Priest, France) and were evaluated at a mean follow-up of 22 months (range, 6–58 months). The authors noted significant difficulty obtaining anatomic fixation of the tuberosities, since secure reconstruction was achieved only in 17 patients (41.5 %). While there was no effect of tuberosity healing on the overall Constant score, patients with tuberosity nonunion and malunion did demonstrate diminished external rotation. When evaluating function according to age, the authors found higher mean anterior elevation (104°) and external rotation (33°) in patients younger than 75 years. Mean anterior elevation and external rotation were 94° and 20° , respectively, in patients older than 75 years. The rate of scapular notching was 25 %, and the overall complication rate was 29.2 %, comprising intraoperative glenoid fracture (1), neuropraxia (5), acromion fracture (1), reflex sympathetic dystrophy (RSD) (3), deltoid dehiscence (1), and anterior dislocation (1).

A multicenter retrospective case series by Lenarz et al. reviewed outcomes in 30 patients (mean age, 77 years) at a mean follow-up of 23 months (range, 12–36 months) [24]. All patients were treated for three- and four- part proximal humerus fractures with a Tornier prosthesis (Edina, MN) at an average of 10 days (range, 1–30 days) following the initial injury. The mean postoperative ASES score was 78 (range, 36–98), and the mean postoperative VAS score was 1.1 (range, 0–5), thus demonstrating excellent pain relief. The authors found significant improvements in active forward flexion (mean, 139° ; range, 90° – 180°) and active external rotation (mean, 27° ; range, 0° – 45°). While the substantial reductions in pain are similar to the results of other studies, active range of motion was significantly better than in other reports. The authors did not correlate these findings with tuberosity status.

A case series by Cazeneuve et al. provided mid- to long-term functional outcomes following use of the Grammont prosthesis in 36 elderly patients (mean age, 75 years) with acute three- or four-part proximal humerus fractures (26 fractures and 10 fracture dislocations) in the setting of osteoporotic bone diagnosed by pathology [25•]. At a mean follow-up of 6.6 years (range, 1–16 years), the authors noted a decline in the mean Constant score when compared with earlier mean follow-up at 6 years. With expanded follow-up, the average scores decreased from 58.5 to 53, and they noted increased evidence of scapular notching and radiographic loosening of the glenoid component (63 %). The overall complication rate was 19.4 %, comprising dislocation (4), RSD (2), and infection (1). Clearly, the functional and radiographic results of this study raise concerns regarding long-term outcomes following treatment with RTSA;

however, it is important to note that this study used an older prosthetic design (Grammont prosthesis) and long-term outcomes with newer designs have not been investigated.

A few comparative studies have reviewed outcomes following primary RTSA relative to shoulder hemiarthroplasty, the current gold standard of treatment. Garrigues et al. recently provided a retrospective review of 19 elderly patients who underwent hemiarthroplasty (9 patients; mean, 69.3 years) or RTSA (10 patients; mean, 80.5 years) following proximal humerus fractures [26]. At a mean follow-up of 3.6 years (range, 1.3–8 years), the authors found that RTSA consistently outperformed shoulder hemiarthroplasty when evaluated with the ASES score (81 vs. 47, respectively), the Penn score (82 vs. 53, respectively), and the SANE score (85 vs. 39, respectively). RTSA patients also demonstrated significantly greater active forward elevation (mean, 122°), as compared with the hemiarthroplasty group (mean, 90°). Active external rotation averaged 33° for the RTSA group and 31° for the hemiarthroplasty group. Interestingly, patients who underwent shoulder hemiarthroplasty had a higher complication rate than did the RTSA group (44.4 % vs. 10 %, respectively). Two patients (22.2 %) in the hemiarthroplasty group developed problems related to tuberosity healing, and both were revised to RTSA.

A study by Gallinet et al. retrospectively compared 17 patients (mean, 74 years) who underwent shoulder hemiarthroplasty and 16 patients (mean, 74 years) who had RTSA performed for fractures of the proximal humerus [26]. At early follow-up, the authors found that the RTSA group demonstrated better abduction (mean, 91°), anterior elevation (mean, 97.5°), and Constant scores (mean, 53). Patients in the hemiarthroplasty group had better glenohumeral rotation (external rotation, 13.5° vs. 9° ; internal rotation, 54.6° vs. 31°), an important observation when analyzing the authors' preferred surgical technique. The majority of patients in the RTSA group (94 %) did not undergo tuberosity reconstruction, since they reported that the fractured tuberosities were excised. This may explain the assertions of other authors that glenohumeral rotation, particularly external rotation, is dependent upon tuberosity healing following RTSA. In fact, a recent follow-up study by the same group compared patients who underwent tuberosity excision or tuberosity fixation during RTSA for fracture treatment. Overall, 66 % of repaired tuberosities healed in anatomic position, resulting in improved external rotation and validated outcome scores (Constant and DASH scores) [27••].

Levy and Badman recently described a technique for facilitating tuberosity healing when using RTSA for primary fracture treatment. The authors proposed that tuberosity healing can be optimized by using a “horseshoe”-shaped humeral allograft accurately fashioned and securely attached to the undersurface of the humeral tray. Overall, the allograft

provides a larger surface area for bone ingrowth around the humeral stem. In a clinical series of 7 patients, the tuberosity union rate was 86 %, resulting in satisfactory active forward elevation (95°–150°) and active external rotation (0°–30°).

Treatment of humeral malunion and nonunion

The treatment of proximal humeral fracture sequelae can be challenging due to significant soft tissue adhesions, joint contracture, and distorted anatomy. Boileau et al. described a fracture sequelae classification that identified prognostic criteria to help determine clinical success for shoulder arthroplasty [28]. In type 3 (surgical neck nonunion) and 4 (severe tuberosity malunion) sequelae, RTSA has been shown to improve functional scores. In a study by Kilic et al., the authors reported a significant increase in Constant scores (9.0 preoperatively to 47.5 postoperatively) for 17 patients with type 3 and 4 fracture sequelae [29]. A similar study by Willis et al. investigated the use of RTSA in 16 patients with proximal humeral malunions [30]. Overall, 62.5 % of patients rated their outcomes as excellent. The total ASES score improved from a mean of 28 to 63 postoperatively, and the VAS pain score improved from a mean of 7 to 3 postoperatively. Significant improvements in range of motion were also observed, since forward flexion improved from 53° to 105°, abduction increased from 48° to 105°, and external rotation improved from 5° to 30°. It is interesting to note that despite the complexity of these cases, there were no postoperative complications. The overall rate of scapular notching was 12.5 %.

On the basis of this literature, there seems to be a role for RTSA in the treatment of proximal humeral fracture sequelae (i.e., malunion and nonunion). Early data suggest improved outcomes relative to similar studies that have investigated postoperative outcomes in patients treated with total shoulder arthroplasty or hemiarthroplasty. In these cases, the most significant factor affecting functional outcomes is greater tuberosity osteotomy, since patients who require osteotomy have been shown to have poor results [31].

Failed shoulder hemiarthroplasty

Until the advent of RTSA, there were few salvage options for patients with poor clinical outcomes following shoulder hemiarthroplasty for proximal humerus fractures. Similar to the subset of patients who present with the aforementioned fracture sequelae in the setting of nonoperative management, patients who fail treatment with hemiarthroplasty present a unique operative challenge. In these cases, patients may demonstrate abnormal glenohumeral alignment, poor bone stock due to glenoid wear, proximal humeral bone loss, rotator cuff insufficiency, and joint contractures.

Currently, there is a paucity of literature investigating clinical success in this specific patient cohort, but the little data available are promising.

Levy et al. recently investigated 29 patients (mean age, 69 years) who initially underwent shoulder hemiarthroplasty for fractures of the proximal humerus but subsequently failed secondary to poor tuberosity healing (malunion, nonunion, or resorption) or glenoid arthritis [32]. The cohort was managed with a single stage revision to a reverse shoulder prosthesis, with or without proximal humeral allograft, and evaluated at a mean follow-up of 35 months. Overall, patients demonstrated significant improvement in the ASES score (total score, pain score, and function score), as well as the Simple Shoulder Test. Significant improvements in range of motion were also observed, since forward flexion increased from 38.1° to 72.7° and abduction improved from 34.1° to 70.4°. Approximately 21 % of the patients were dissatisfied with their outcome; however, it should be noted that the majority of these patients (4 out of 6) were treated with RTSA alone in the setting of significant proximal humeral bone loss. The authors encouraged the use of proximal humeral allograft in these cases to provide additional rotational and structural stability in order to diminish stress on the humeral component and increase the lateral offset to improve the deltoid moment arm. Additionally, the allograft provides structural subscapularis tendon that can be incorporated into the final subscapularis repair.

Lollino et al. investigated similar outcomes in patients who underwent RTSA for revision of failed shoulder hemiarthroplasty or ORIF following three- and four-part proximal humerus fractures [33]. Utilizing validated outcomes and functional testing, the authors found that while clinical outcomes were notably better following ORIF, there were significant improvements in both groups and the overall outcomes were not influenced by the initial method of surgical treatment.

Conclusion

Unreliable clinical results achieved with shoulder hemiarthroplasty in the setting of complex proximal humeral fractures have prompted attempts to treat specific patients with RTSA. Indications for the use of RTSA have been elucidated in recent studies and include age greater than 70 years, severe tuberosity comminution, advanced osteoporosis, pre-existing rotator cuff pathology (fatty infiltration, tendon tear), and significant medical comorbidities that may compromise tuberosity healing. The cumulative experience to date suggests reliable pain relief and improved patient satisfaction due to better range of motion and function, when compared with shoulder hemiarthroplasty. Further randomized,

longitudinal studies will help define the future role of RTSA in this patient cohort.

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