Management of Revision Reverse Shoulder Arthroplasty

Brian H Goldman, DO1, Abby L Halpern, DO1, Matthew J Deal, BS2, Bradley P Richey, MS2, Eric M Mason, BS2, Hari O Gupta, DO, MSc1, Jonathan Callegari, DO3, and Cesar J Bravo, MD4

Abstract
Background: The number of reverse total shoulder arthroplasty procedures performed has increased in recent years due to expanding surgical indications. There has been a proportional increase in complications, with reported complication rates for a revision reverse total shoulder arthroplasty as high as 68%. Revising a reverse total shoulder is a complex procedure requiring significant preoperative planning.

Methods: A literature review of revision shoulder arthroplasty techniques was performed. No IRB approval was needed for this study.

Results: Instability is the most common reason for revision reverse total shoulder arthroplasty followed by infection. Revision arthroplasty is also needed in the setting of bone loss, aseptic loosening, and periprosthetic fracture. Each case requires a comprehensive preoperative plan to address each deformity for a successful result.

Conclusions: For this procedure to be successful, it is imperative that the physician understands the risk factors, identifies the cause, and is familiar with current surgical techniques. This study reviews both preoperative and perioperative management of reverse total shoulder arthroplasty in the revision setting.

Keywords
Reverse total shoulder arthroplasty, revision arthroplasty, glenoid bone loss, humeral bone loss, allograft-prosthesis composite, periprosthetic fracture, prosthetic joint infection

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Introduction
There was a 5-fold increase in the number of patients undergoing reverse total shoulder arthroplasty (RTSA) between 2004 and 2012 in the United States.1 Estimates indicate that 30,000 RTSAs were performed in 2012, with RTSA accounting for 42% of all shoulder arthroplasties.1,2 Although the most common indication for RTSA is rotator cuff arthropathy, additional indications include acute proximal humerus fractures, chronically locked glenohumeral dislocations, upper extremity pseudoparalysis, glenohumeral arthritis with severe glenoid bone loss, inflammatory arthritis, proximal humerus fracture malunion/nonunion, failed shoulder arthroplasty, and tumors.3–5

Historically, complication rates following earlier RTSA designs were extremely high; with newer implants, complication rates have decreased, but are still high, ranging from 19% to 68%.4 Complications include scapular notching, glenoid component complications (eg, loosening), hematoma formation, infection, instability,
neurological deficits, acromial stress fractures, and humeral component complications. With increasing RTSAs being performed, this, in turn, leads to a higher number of revisions, with rates of 10% and 16% in the primary and revision settings, respectively. Zumstein et al. determined that prosthetic instability was more than twice as likely following RTSA revision procedures than in primary cases (9.4% vs 4.1%). Furthermore, up to 22% of revision procedures require additional revision, and these procedures generally result in lower functional outcome scores and decreased range of motion.

This review summarizes the most relevant advances in the field of revision RTSA. This includes the factors that predispose to failure including infection, glenoid bone loss, proximal humeral bone loss, and soft tissue deficiency. The goal is to familiarize orthopedic shoulder specialists with preoperative planning, infection management, techniques to address instability, periprosthetic fractures, and salvage options for failed revision RTSA.

**Preoperative Planning**

The preoperative planning strategy depends on the etiology. Potential etiologies include implant loosening, infection, humeral shortening from bone loss, or excessive glenoid medialization. When planning a revision, X-rays of the entire implant need to be obtained. Additionally, comparative humeral length scanogram X-rays can help identify shortening, while comparative true anterior–posterior (AP) shoulder X-rays can demonstrate humeral and/or glenoid medialization. Computed tomography (CT) scans can be used to assess glenoid medialization, implant orientation, available bone stock, and degree of fatty infiltration in rotator cuff musculature. CT scans are required if three-dimensional templating software will be used. Such software allows the surgeon to develop patient-specific virtual guides which are then utilized in the live procedure. Magnetic resonance imaging can be used to evaluate the soft tissues, and electromyography and nerve conduction studies can be obtained if axillary nerve injury is suspected. If bone graft is needed, the choice of autograft versus allograft should be discussed with the patient. Finally, to rule out infectious etiologies, studies such as complete blood count, erythrocyte sedimentation rate, C-reactive protein, bone scan, and joint aspiration may be helpful, but biopsy remains the gold standard.

**Complications**

**Infection**

After instability, infection is the second most common complication requiring RTSA revision. If infection is suspected, intraoperative antibiotics need to be held until 5 intraoperative culture samples are obtained. The most common offending pathogens are *Staphylococcus epidermidis*, *Staphylococcus aureus*, and *Cutibacterium acnes*. *C. acnes* blood culture requires an incubation period of 10 to 14 days. A polymerase chain reaction assay can be used to detect this pathogen within 24 hours and avoid delay.

Management of the infection differs for acute and chronic infections. Acute infection (within 3 months of surgery) requires irrigation, debridement, and replacement of the polyethylene and glenosphere. Chronic
infection (an infection occurring > 3 months postoperatively) requires implant removal and replacement. Implant replacement may not be undertaken if the patient has a multidrug-resistant organism and/or failed both revision and antibiotic treatment.\textsuperscript{3,5,12} 

In the event of chronic infection, a revision will need to be performed. It is not yet known if a single- or 2-stage revision leads to better clinical outcomes. Single-stage revisions have better functional outcomes but an increased risk of persistent infection. Therefore, they require long-term antibiotics and increased clinical vigilance to decrease the risk. Sevelda and Fink created a 1-stage treatment algorithm that involved explantation of the implant, debridement, antibiotic-loaded cement, placement of new implant, and systemic antibiotics.\textsuperscript{13} This algorithm was determined to be safe and successful in 93\% patients at 5 years.\textsuperscript{13} Two-stage revisions are generally preferred over 1- or 3-stage revisions, despite their higher morbidity rate. By utilizing an articulated antibiotic-bearing polyethylene cement, 2-stage revisions preserve soft tissue tension while decreasing infection risk. Cases with persistent draining sinus and partial treatment developing a secondary film around the bone–implant interface require debridement and removal. This makes 2-stage revisions particularly effective in the setting of chronic infections, revision to a reverse component, and cases of drug resistant bacteria.\textsuperscript{12} However, Grubhofer et al. appreciated comparable success rates between single and staged revisions even in cases of unknown infectious etiology.\textsuperscript{14} 

Tseng et al. developed a 3-stage shoulder revision protocol to address persistent infections.\textsuperscript{15} The first stage included implant explantation, tissue cultures, debridement, cement removal, cement spacer insertion, and intravenous (IV) antibiotic treatment. The second stage consisted of limited debridement and additional culture sampling. In the event of positive cultures or purulence during a previous stage, a formal debridement and an additional course of IV antibiotic treatment were given. Reimplantation took place in the third stage, assuming there were no clinical signs of infection and open biopsy cultures were negative. The results of the 3-stage protocol were promising, demonstrating similar range of motion and subjective outcomes when compared to revision RTSA procedures in aseptic cases.\textsuperscript{15} 

**Glenoid Bone Loss**

Glenoid bone loss may stem from scapular notching, osteolysis around a loose glenoid component, arthritis, osteoporosis, or altered kinematics following surgery.\textsuperscript{3,5,8} This is particularly true for larger patients in which using a small glenoid implant decreases deltoid coaptation and increases humeral medialization, ultimately impairing stability and increasing risk for bone loss.\textsuperscript{12} It follows, then, that glenoid medialization can be caused by bone loss due to excessive reaming and/or osteolysis. Whatever the etiology, if the glenoid bone loss results in humeral medialization (<15 mm), a larger glenosphere with or without bone graft should be substituted.\textsuperscript{12} Tashjian et al. presented 3 cases in which recalcitrant instability was managed by attaching the humeral implant to the glenoid with high strength nonabsorbable suture cerclage.\textsuperscript{16} This was done in combination with retensioning and removing any impinging soft tissue.\textsuperscript{16} 

In cases of mild bone loss, it becomes necessary to utilize the remaining scapula bone present to improve prosthesis stability. Klein et al. described directing the central screw along the scapular spine centerline instead of perpendicular to the glenoid face in order to compensate for glenoid bone loss.\textsuperscript{17} Screw design may help improve utilization of deep bone by using screws of varying diameters as larger diameter peripheral screws have been designed to improve purchase.\textsuperscript{3,11,18–20} Larger glenoid bone defects require bone graft. Cancellous bone graft can be used in cases of central bone loss with an intact glenoid rim (Figure 2). When the cortical glenoid rim is deficient, corticocancellous autograft is oriented with the cortical component facing laterally in order to prevent glenoid component medialization.\textsuperscript{21} For small peripheral glenoid-contained defects that require less than 15° of correction, eccentric

![Figure 2. Impaction grafting of the glenoid for a large contained bony defect.](image-url)
reaming can be used to create a flat surface for the baseplate to be implanted. \(^8,^{22}\)

In cases of large peripheral defects, grafting options include autograft from the ipsilateral iliac crest or fresh-frozen femoral head allograft to match the glenoid defect. \(^8,^{22}\) Iannotti and Frangiamore utilized a polymethyl methacrylate mold to shape fresh-frozen femoral head allograft with a burr and saw. \(^23\) The results of this method were variable which lead to concern that excessive graft was being reabsorbed or inadequate graft was being incorporated. In patients with appreciable incorporation, conversion to reverse arthroplasty was possible due to increased available glenoid bone stock. \(^23\)

Mahyris et al. compared structural and nonstructural bone graft in revision RTSA procedures, and iliac crest autograft demonstrated good clinical and radiographic outcomes on short-term follow-up without increased risk for glenoid component failure. \(^24\) Graft fixation refractory to use of available peripheral screws may require use of separate wires or screws; otherwise, there are glenoid revision baseplates with attached plates and additional holes to allow for graft fixation. \(^25\)

Glenoid revision can occur in a single stage if a stable baseplate can be implanted. However, this is usually performed in 2 stages; bone grafting occurs during the first stage, followed by glenoid component implantation during the second stage 3 to 6 months later. \(^8\) Insertion of the glenoid component and bone graft without placement of the humeral component avoids potential excessive glenoid shearing stress, thus minimizing risk of nonunion or malunion. \(^20\)

In efforts to reduce the incidence of 2-stage revision, Norris et al. described a technique to acquire tricortical iliac crest autograft and achieve immediate fixation of graft to the baseplate. \(^20\) This is achieved by implanting the baseplate to the patient’s iliac crest and then removing the graft in situ (attached to the baseplate). \(^20\)

Glenoid baseplate augmentation is another option when dealing with bone loss, and it may provide a simpler bone-preserving option compared to other techniques. Augments are customizable and may produce a lower complication rate than bone grafting with regard to scapular notching, disease transmission, and host incorporation. \(^26,^{27}\) However, they may be costly and may increase bone-implant forces. Ivaldo et al. described another technique where a customized porous tantalum device is fixed to the metal back of the glenoid component for management of glenoid bone loss and medialization, with good patient satisfaction and return to daily activities. \(^28\) In cases of a contained glenoid defect with extensive glenoid medialization, impaction grafting is an option; either allograft bone chips or autograft bone can be used in conjunction with baseplate augmentation.

When glenoid medialization leads to instability, soft tissue tensioning and modifying component placement may improve patient outcomes. A retrospective study by Tashjian et al. found an association between instability and superior baseplate inclination causing inferior impingement; thus, the baseplate should be inferiorly inclined to avoid this complication. \(^29\) Another retrospective study demonstrated a significant difference in tilt between atraumatic and traumatic instability groups. This study advised creating 10\(^\circ\) of inferior tilt of the glenoid component. \(^9\) Inferiorly placed glenospheres were previously proposed to lengthen the humerus. Clouthier et al. found that by increasing socket depth and using eccentric inferior-offset of the glenosphere, stability increased by 17\%. \(^30\) Apart from reducing scapular notching, lateralization of the glenoid demonstrated an increase in force needed to cause anterior dislocation for each incremental increase in lateral offset (5, 10, and 15 mm) as described by Henninger et al. \(^31\) This was at the expense of increased deltoid force needed for abduction, increasing the risk of deltoid pain and acromial stress fractures. \(^31\) However, Giles et al. showed that humeral lateralization countered the negative effects of glenosphere lateralization by decreasing deltoid forces needed for active abduction in a cadaveric study. \(^32\)

**Proximal Humeral Bone Loss**

Proximal humerus bone loss may result from infection, malignancy, osteolysis from polyethylene debris, fracture sequelae, shortened hemiarthroplasty (HA), post tumor humeral resection surgery, or iatrogenically during removal of the humeral prosthesis. \(^8,^{12}\) Humeral bone loss is likely to result in the loss of soft tissue attachment sites, contributing to shoulder instability by decreasing both deltoid contour and soft tissue tensioning. \(^8,^{33}\) Such losses can be extremely detrimental to the function of the shoulder.

Determining proximal humerus bone loss can be accomplished by comparing contralateral humeral radiographs using markers as described by Lädermann et al. \(^34\) (Figure 3) or intraoperatively through joint stability and range of motion. \(^34\) After the glenoid component is implanted, a sponge is used to provide enough friction between the stem and the canal to allow for adjustments of stem version and height for trialing. The shoulder is reduced, and stability and range of motion are assessed to determine whether the humeral component needs to be shortened or lengthened. \(^8\)

Implant modification or cementoplasty can be used to address small proximal humerus loss. Cases with bone loss >5 cm can be addressed with a structural allograft composite or massive prosthesis with tuberosity modularity, in efforts to restore the deltoid wrapping angle, improve the abduction moment arm, and increase the recruitment of the posterior deltoid for external rotation. \(^12,^{35}\) Boileau
et al. also approached humeral bone loss based on the size of the defect. Bone loss < 5 cm in an elderly patient can be managed with a cement collar around the implant referred to as a “cementoplasty reconstruction.” In cases of 5 to 15 mm bone loss without implant malpositioning or loosening, a metal-polyethylene spacer can add 15 mm without needing to exchange implants. Changes on the glenoid side can be made to lateralize and lengthen the humerus if there is less than 15 mm of shortening. These changes involve using a larger glenosphere and/or inferior positioning of the glenosphere.

Use of a humeral allograft, such as a proximal humeral allograft—reverse shoulder allograft-prosthesis composite (APC), is required in cases of > 50 mm of bone loss. The APC helps protect the implant from excessive rotational stress, helps restore deltoid kinematics, and provides an attachment site for soft tissue repair. Acceptable functional outcomes with an APC have also been achieved in cases requiring tumor resection.

APC implantation involves making a transverse cut along the remaining humerus, followed by reaming to allow space for a cement mantle. The allograft length is determined by measuring from the implant shoulder to the transverse cut. Allograft preparation includes an anatomic neck cut with desired inclination and version. The stem is cemented into the graft and then cemented into the native humerus. Another described fixation technique involves fixing the allograft to native bone first with a step cut and cerclage cables (Figure 4). Chacon et al. described a method of creating a lateral bone plate by making cuts that leave 5 cm of bone laterally and 1 to 2 cm medially.

A 3.5 mm locking compression plate can be used to provide interfragmentary compression and address the rotational instability of the APC. If osteoporotic bone is present, use of tibial or fibular strut allografts may be useful when utilizing cerclage cables. Stephens et al. demonstrated that revision RTSA can be managed without use of allograft. Their patients had an average proximal humeral bone loss of 3.63 cm. This group recommended use of a cemented long-stem monoblock humeral prosthesis in the setting of humeral bone loss.

It is generally advised in the revision setting to use a long-stem revision humeral implant that extends 2.5 humeral diameters past the osteotomy in a press-fit or cemented fashion (Figure 5). This may allow for additional fixation such as when plates and screws are used to address rotational forces within the allograft humeral fixation interface.

Fractures
In a meta-analysis by Zumstein et al., the incidence of periprosthetic humeral fractures in RTSA was 3.45%.

Figure 3. Schematic for determination of the implanted prosthesis height during preoperative planning. A, Length of the contralateral humerus. B, Length of the preoperative humerus. C, Corrected length of the extremity after implantation of the prosthesis. The distance between the points P and H is the distance in millimeters that must be measured at the time of implantation between the lateral cortex of the humerus and the superolateral part of the metallic stem. Reprinted from Lädermann et al. DI, diaphyseal axis; EF, enlargement factor; EL, epicondylar line.
Fracture management depends on fracture pattern, amount of displacement, and presence of instability. Displaced transverse humerus fractures are treated with plate osteosynthesis with incorporation of an autologous bone graft. If there is a transverse or spiral humeral fracture with minimal displacement, splint immobilization with neutral rotation is utilized (Figure 6). In cases with concomitant instability or loosening, long-stem revision is advised to bridge the fracture site.\textsuperscript{12}

According to Patterson et al., postoperative fractures of the acromion and scapular spine both have an incidence of 4\%.\textsuperscript{39} Acromion fractures should initially be treated conservatively with immobilization because both nonoperative and operative management produce similar outcomes.\textsuperscript{39} Crosby et al. developed a scapular fracture classification system for postoperative RTSA patients to guide treatment.\textsuperscript{40} Type I is an avulsion of the anterior acromion and are managed nonoperatively. Type II are fractures of the acromion, posterior to the acromioclavicular joint, and should be managed with joint resection for stable fractures or joint resection with open reduction internal fixation (ORIF) if the fracture is unstable. Type III are scapular spine fractures occurring after traumatic events and are universally managed with ORIF without the use of the superior baseplate screw.\textsuperscript{40}

**Salvage**

In a study by Casier et al., several RTSA patients underwent conversion to HA, spacer, or megahead prosthesis.\textsuperscript{41} However, the article deemed RTSA revision to be a superior option as the salvage procedures produced poor functional outcomes and inadequate pain relief. Similarly, Muh et al. reported insignificant pain relief and poor patient outcomes following resection arthroplasty.\textsuperscript{42} Conversely, Gamradt et al. reported adequate pain relief for conversions to both HA and cement spacers, though poor functional outcomes and an increased incidence of anterosuperior escape were described.\textsuperscript{43} Overall, salvage procedures have been supported as options when revision RTSA is not feasible; however, patients should be educated that functional results and pain relief are variable.

**Sequelae From Long-Term Instability**

The reported instability rate after RTSA revision for dislocations requiring surgical intervention is 32\% to 45\%.\textsuperscript{44,45} Late instability is attributable mostly to asymmetric polyethylene wear secondary to mechanical impingement.\textsuperscript{44,45} Cheung et al. found placement of a thicker polyethylene insert failed to resolve the problem in 45\% of their cohort, delineating the need to assess other variables in the revision or post-traumatic setting.\textsuperscript{44} Previous open shoulder operations and those with complex diagnoses pose a significant challenge for restoring dynamic soft tissue constraints. The deltoid provides the primary compressive forces across the RTSA articulation and in a revision setting and is often atrophied due to disuse and partial denervation, making tensioning difficult. In a revision setting, innate stability is often
Figure 5. The authors provide a case example of a failed hemiarthroplasty in the setting of a suspected infection that was successfully treated with an RTSA APC. A, Loose implant. B, Retrieved implant. C, Humeral bone loss. D, Spacer placement. E, RTSA APC construct. F, AP and axillary radiographs taken at 6-month postoperative follow-up.
compromised. Methods of restoring humeral length and achieving glenoid lateralization will likely temper persistent instability in the revision setting. A major complication of instability is dislocation. Identifying RTSA dislocation with radiographic imaging requires a true AP, lateral transthoracic, and axillary views of the shoulder. Bilateral humerus views help determine humeral bone loss and humeral medialization with the humeral axis >15 mm medial to the lateral border of the acromion. A shoulder AP glenoid view demonstrates implant position and inferior subluxation if there is inadequate soft tissue tensioning. The axillary views help with determining frank dislocation and allows for assessment of glenosphere version. In lateral views, a stable implant will show the center of the humeral baseplate in front of the glenosphere; a loss of overlap reveals instability. Shoulder CT scans can identify impingement due to bone, heterotopic ossification, and acromion fractures which can all lead to instability. In cases of instability, ultrasound of the subscapularis can identify failure of repair or infection.

Teusink et al. reported that early RTSA dislocation managed conservatively with closed reduction and immobilization using an abduction splint was as effective as undergoing surgical revision. Conversely, dislocations after 3 months generally occur because of insufficient deltoid tension and should be managed with surgical revision.

Conclusion
Revision of a failed RTSA is challenging. A revision procedure requires extensive consideration of surgical approach, bone preservation methodology, implant removal and fixation techniques, and management of possible postoperative complications. Various techniques to deal with these complications are presented in this review. By considering the variables affecting revision RTSA and planning accordingly, the orthopedic surgeon can be confident in performing a successful revision procedure.

Abbreviations
RTSA = Reverse total shoulder arthroplasty
AP = anterior-posterior
CT = computed tomography
AC = acromioclavicular
RA = resection arthroplasty
HA = hemiarthroplasty
C. acnes = Cutibacterium acnes

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ORCID iD
Matthew J Deal https://orcid.org/0000-0003-3143-7080

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