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SHOULDER SURGERY: COMPLICATIONS (X LI, SECTION EDITOR)

Management of complications after revision shoulder arthroplasty

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Abstract Complications after revision shoulder arthroplasty are similar to those in the primary setting which include instability, fracture, bone loss, infection, nerve injury, and loosening. Unlike in the primary setting, however, the rate of complications for revisions is significantly greater and the management is more complex because of overlapping complications and limited treatment options. Furthermore, there is a paucity of evidence-based literature to direct the management options in these patients. The purposes of this review are to broadly outline the major complications that are seen in revision shoulder arthroplasty and to provide general principles on how to recognize and approach these complex cases.

Keywords Revision · Complications · Shoulder arthroplasty · Management

Introduction

With the growing number of shoulder arthroplasties in the USA [1], complications that lead to the need for revision arthroplasty are reasonably well defined. Complications after revision shoulder arthroplasty are similar to the complications seen after primary shoulder arthroplasty but are more frequently encountered and difficult to manage. Sometimes defining the cause of failure, especially if the main symptom is pain, is complex and multifactorial. Overall, studies have shown that revision arthroplasty has less predictable functional outcomes and increased complication rates compared to primary shoulder arthroplasty [2–5].

Management depends on defining the complication and the etiology and then taking stock of the remaining current anatomy in trying to apply either a surgical or nonsurgical solution. In these complex situations, surgery is not always the best option given the high complication risks associated with a re-revision setting. The situation is further complicated by the fact that revision arthroplasty can either be a reverse or anatomical prosthesis and the approach to each is unique. The focus of this review is to break down some of the most common issues after revision shoulder arthroplasty and assess the management of these issues in a principled approach.

Complications of revision arthroplasty

Instability

With an anatomic prosthesis, instability is due to subscapularis failure until proven otherwise after a revision. In the primary setting, the most common rotator cuff tear is a subscapularis tear. Miller et al. showed that the prevalence of postoperative subscapularis tear is 6 % and that all patients in their study required surgical repair [6]. However, this tear rate is likely higher in the revision setting. Subscapularis muscle or tendon disruption can lead to anterior displacement of the prosthesis and poor functional outcomes and pain (Fig. 1). Posterior instability is less common than anterior instability after arthroplasty and in most cases is related to preoperative glenoid erosion and posterior subluxation. The classification proposed by Walch et al. defined different glenoid morphologies in primary glenohumeral arthritis and found this pathology to correlate with excessive retroversion and humeral

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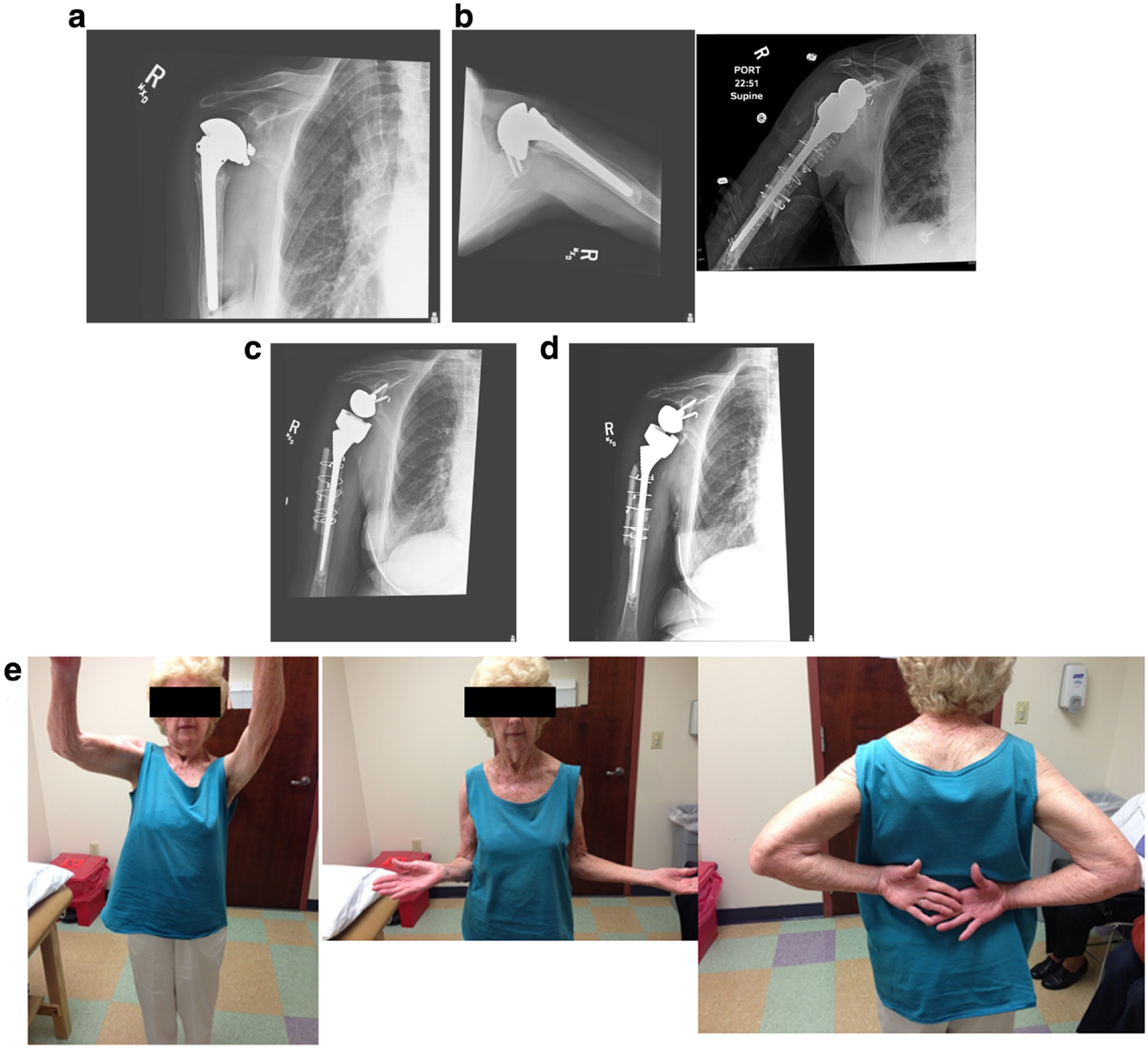

Fig. 1 Case of a revision surgery for recurrent instability after hemiarthroplasty for proximal humerus fracture and attempt at allograft to the glenoid. **a** Presentation films with preoperative AP and axillary radiographs demonstrating a cemented hemiarthroplasty with tuberosity resorption and anterior humeral subluxation. **b** Revision to RSA was complicated by proximal humerus comminution after osteotomy for cemented implant extraction. Femoral strut allograft with cerclage wires and a long, cemented stem was placed. Positive cultures for *P. acnes* noted after 14 days of incubation with negative preoperative and intraoperative markers. **c** One year and **d** 3 years follow-up demonstrating prosthesis in good position with the incorporation of femoral strut allograft. Note the heterotopic bone formation at the inferior glenoid, but no bone loss or "notching". **e** Acceptable functional results at 3 years follow-up with one out of ten pain on VAS

subluxation [7]. Sanchez-Sotelo et al. reported the results of 33 shoulders (hemiarthroplasty in seven and TSA in 26) with recurrent instability and their outcomes. In this particular group, the authors noted 19 shoulders had anterior instability and 14 shoulders had posterior instability. The majority of the instability was attributed to abnormal capsular tensioning or rotator cuff dysfunction. Revision surgery was only able to restore stability in nine of the 32 shoulders (28 %) and anterior instability had a higher failure rate. The authors concluded that instability after total shoulder arthroplasty (TSA) is a difficult problem to manage and even with revision surgery, more than half of the patients in this study remained unstable [8]. Component sizing can also play a role such that an undersized component can lead to laxity of the soft tissues which can compromise the tensioning of the components. Though, unless grossly undersized, this is rarely the cause of instability.

Instability after a reverse shoulder arthroplasty (RSA) also may be related to soft tissue abnormalities, such as

subscapularis insufficiency or inadequate deltoid or rotator cuff tensioning. Also, component positioning, such as excessive anteroversion of the stem, can contribute to instability. Implant design has also been implicated in scapular notching and instability in terms of the position of the baseplate relative to the center of rotation and neck-shaft angle of the prosthesis [9, 10]. Chalmers et al., however, found that the most common risk factors for early dislocation after RSA were subscapularis deficiency, previous surgery, male gender, and a BMI >30 [11]. Edwards et al. also reported a significantly higher risk of dislocation after the reverse shoulder arthroplasty if the subscapularis tendon is not repaired at the time of primary surgery [12]. Instability is a common cause for revision of a reverse shoulder arthroplasty. Boileau et al. found that instability accounted for 48 % of all complications in those requiring revision of a RSA [13].

Fracture

The incidence of periprosthetic humerus fracture can range between 0.6 and 3 % in primary shoulder arthroplasty [14]. Revision arthroplasty places the patient at significantly higher risk for intraoperative periprosthetic fracture because of inadequate bone stock. Significant risk factors include female sex, osteopenia, and press-fit humeral implants [15, 16]. Typically, fractures occur on the humeral shaft at the mid to distal diaphysis. This can be due to excessive torsion of the shaft in an attempt to expose the humeral head. It can also occur in the proximal metaphyseal region due to excessive impaction of components, extraction of implants, or during retraction to expose the glenoid [14, 17•, 18].

Postoperative periprosthetic fractures of the humerus are classified using the Wright and Cofield classification, which is based on the location of the fracture relative to the tip of the humeral prosthesis. Type A fractures are centered near the tip of the stem and extends proximally. Type B fractures are centered at the tip of the stem and extend distally. Type C fractures are distal to the tip of the stem [15, 17•].

Bone loss

In revision cases, bone loss can be unpredictable and occurs on both the glenoid and humeral sides. Some common causes of bone loss include osteolysis from polyethelene wear, removal of cemented or press-fitted implants where bone is lost with active removal of cement or from bone on-growth, glenoid erosion in the setting of a hemiarthroplasty, and tuberosity nonunion and resorption after treatment of a proximal humerus fracture (Fig. 1). In the revision setting, bone loss poses significant problems for fixation of a cemented glenoid, reverse baseplate, or humeral stems [19, 20, 21••, 22, 23].

Infection

The incidence of infection in primary total shoulder arthroplasty is reported to be between 0.4 and 2.9 % while for reverse total shoulder arthroplasty, rates range from 1 to 10 % [21••]. In revision shoulder arthroplasty, the rate of infection has been reported to be as high as 15.4 % [24–26]. Patients at risk for infection include those with diabetes mellitus, rheumatoid arthritis, corticosteroid use, and previous shoulder surgery. Classifying infection after revision surgery is similar to the primary setting, but the system must also account for positive cultures at the time of revision surgery when preoperative workup is negative. Sperling et al. proposed a classification that includes this particular scenario and considered it a type 1 infection. Type 2 infections are identified within 30 days after surgery and are considered acute. Type 3 infections are acute hematogenous infection identified more than 30 days after surgery. Type 4 infections are chronic infections [27]. In the scenario of late culture positivity with organisms of low virulence, Mook et al. proposed a modified classification with the addition of the acronym FACP (failed arthroplasty with positive cultures) [26].

Type 1 infections are particularly problematic given the culture results are not available until the final culture readings at least 14 days after surgery (the minimum recommended incubation period for *Propionibacterium acnes* (*P. acnes*), a characteristic organism for shoulder arthroplasty infections). Management is therefore complicated with the prosthesis already in position. Clinical and laboratory indicators of infection are subtle or absent, and purulence is rarely observed intraoperatively, making *P. acnes* difficult to diagnose [26, 28]. Additionally, the growth of bacteria does not appear to always represent infection [29]. Levy et al. studied 55 patients undergoing primary total shoulder arthroplasty by taking culture at the time of surgery. Forty-one percent of these patients grew out *P. acnes*. The implication of these results is not totally clear; however, the data may imply that these low virulence bacteria may colonize the native joint and not be a cause of infection in some if not many cases [30].

Nerve injury

Iatrogenic nerve injury can occur in a number of ways during revision cases because of increased soft-tissue scarring after multiple surgeries and poorly defined tissue planes. Direct injury can occur during dissection, cement extrusion in the humeral shaft leading to nerve injury has also been reported [31], but the most common etiology is likely secondary to brachial plexus traction.

In the setting of revision cases, these traction injuries are more frequently encountered then in primary arthroplasty due to the length of the procedure and prolonged retraction. Nagda et al. used intraoperative nerve monitoring during shoulder

arthroplasty and stated that placing the arm in position of extreme extension, external rotation, and abduction/adduction should be limited to reduce nerve compromise. They found that patients with prior surgery and limited external rotation were at increased risk of nerve injury, though nerve monitoring is not needed routinely [32] Lynch et al. used neuromonitoring during shoulder arthroplasty and found alerts frequently involving the axillary and musculocutaneous nerves. This can be attributed to the stretch placed on the brachial plexus during humeral positioning and traction during glenoid exposure [33]. Ladderman et al. found the prevalence of acute postoperative nerve injury to be significantly more frequent in RSA than in anatomic TSA due to arm lengthening in RSA [34]. In the majority of these cases, however, neurapraxia is the cause and with conservative management, symptoms will completely resolve with time.

Loosening

There is limited literature on loosening of components in the revision setting, and therefore, we need to extrapolate the literature for loosening in the setting of primary shoulder arthroplasties. The most common cause for revision of a TSA is glenoid component loosening. Factors that contribute to glenoid loosening include infection, component malposition, component design [35–39], glenohumeral instability [40], and excessive radial mismatch of the glenoid and humeral component [41, 42]. Radiolucent lines surrounding the glenoid component can indicate, but does not necessarily suggest, loosening. As defined by Nagels et al., radiolucency 2 mm or more or a shift in the component suggests radiologic loosening [43].

In reverse shoulder arthroplasty, baseplate loosening and migration can be due to osteolysis from polyethylene wear debris produced by scapular notching. This is encountered in the Grammont-style prosthesis due to the medialized center of rotation and can be seen in 68 % of cases [44].

Loosening of the humeral stem is a less common finding than glenoid loosening in shoulder arthroplasty. Humeral loosening alone infrequently requires revision, with glenoid loosening usually a concomitant issue [45]. Radiolucent lines are frequently seen at the tip of the humeral prosthesis with the use of press-fit stems [46, 47]. However, the clinical outcomes do not always seem to correlate with the presence of radiolucencies around the humeral component [47–50]. Cuff et al. found that 3 % of patients with reverse shoulder arthroplasties had asymptomatic humeral stem loosening at a minimum of 5 years follow-up [51]. Humeral component loosening is seen more frequently in reverse total shoulder arthroplasties than in anatomic shoulder arthroplasties due to the semiconstrained design of the prosthesis, offering more stress at the bone-stem interface [52].

Management of complications

Instability

In the setting of an anatomic shoulder arthroplasty, anterior instability is most commonly caused by subscapularis disruption. Direct repair can be attempted if healthy tissue is still present. However, in a patient that underwent multiple surgeries, poor tissue quality is often encountered. Augmentation and reconstruction of the subscapularis has been described using Achilles allograft, though risk of limited range of motion and further instability can be seen [53, 54]. In the subset of patients with static anterior instability, outcomes after a pectoralis major transfer are often poor and unpredictable [55, 56]. Posterior instability due to capsular laxity can be managed with capsular plication. Or, if soft tissue imbalance is present with tight anterior structures causing posterior instability then release of the subscapularis, anterior capsule, or the upper portion of the pectoralis major can be performed [57]. Revision surgery for posterior instability has a higher success rate than anterior instability, though both types of procedures have moderate success rates overall [8].

Dislocation after a RSA should initially be managed by closed reduction and sling immobilization with restriction of adduction, extension, and internal rotation for a brief period of time. If this first-line treatment fails, evaluation of implant position and soft-tissue tensioning should be conducted. Inferior soft-tissue impingement can likely be the cause of instability, and removal of this tissue is often necessary, though in the revision setting, heterotopic bone and scarring can make this difficult. When revision surgery is required, placement of a larger glenosphere to provide adequate tensioning or the use of a larger, more constrained humeral component may be needed [58].

Recurrent instability cases may need salvage procedures to provide adequate stability, pain relief, and function. With rotator cuff insufficiency in anatomic TSA, revision to a RSA is often the best option since the design is semiconstrained and relies less on the rotator cuff and capsule. Typically, those who receive RSA as a revision arthroplasty have higher complication rates than those who receive it as a primary arthroplasty [59]; however, revisions for instability have generally better outcomes [22] (Fig. 1). Resection arthroplasty can also be done as a salvage procedure for pain relief in those with recurrent instability, but patients typically have poor range of motion and function.

Fracture

Intraoperative fracture

Intraoperative fracture of either the humerus or glenoid often requires a change of course. After a glenoid fracture, it is

important to assess whether there is enough bone stock for placement of a glenoid component for an anatomical arthroplasty or whether conversion to a reverse arthroplasty is necessary. Fixation can be readily established with a baseplate due to the long centralized screw that can bypass either deficient or fractured bone and obtain purchase in the scapula [23, 60].

Intraoperative humeral fractures can be more challenging. If a greater tuberosity fracture occurs (as it often does in explanting a previous stem) with the hope of placing an anatomical TSA, it is critical to determine if the fracture is repairable and if the attached rotator cuff is functional. If not, conversion to a RSA is necessary. Therefore, it is essential to have all of the implant options available in the operating room during these complex revision shoulder arthroplasty cases. Van Thiel et al. described using a vertical humeral osteotomy for stem extraction. In their study, no perioperative or postoperative fractures were seen at an average of 41 months of follow-up [61].

Humeral fracture can also occur during implantation of the stem. In this case, it is important to make sure the stem is stable. Often wiring is sufficient—but sometimes cementing the stem is necessary. Fractures below the tip need longer exposure, open reduction and internal fixation (ORIF) with cerclage wires or a plate (or strut grafting) with a long, press-fit revision stem (ideally). There are few of these on the market, and therefore, a long, cemented stem may be needed. The surgeon must be cognizant of cement leakage when revising humeral shaft fractures, which can prevent fracture healing or can injure the radial nerve.

Postoperative fracture

Nonoperative management of the humerus can be carried out with nondisplaced fractures with a well-fixed prosthesis or fractures distal to the tip of the humeral stem with acceptable radiographic alignment. Acceptable radiographic alignment is defined as within 20° of anterior/posterior angulation, 30° of varus/valgus alignment, and 20° of rotational alignment [62]. Nonoperative treatment can be carried out with a humeral fracture brace in these circumstances. ORIF should be considered for type C fractures that do not meet acceptable radiographic alignment criteria. ORIF should also be considered for displaced, unstable fractures centered at the tip with a well-fixed humeral implant due to high nonunion rates when treated nonoperatively [62]. Fractures proximal to the tip with humeral stem loosening should be treated with a revision to a long-stem prosthesis that bypasses the fracture site by two cortical diameters. Treatment can be augmented with strut graft and cerclage wires [63].

Bone loss

Glenoid bone loss

Preoperative planning in the setting of glenoid bone loss includes the use of CT scan with 3D reconstruction or 3D scapula models to assess the extent of bone loss and available glenoid bony anatomy. This can offer insight to proper pin placement for glenoid implantation and positioning. The use of preoperative three-dimensional surgical simulation and patient-specific instrumentation can also be helpful [64–66].

Intraoperatively, adequate bone stock can determine whether glenoid reimplantation can be considered or if bone grafting is required. The classification by Antuna et al. is commonly used to assess intraoperative glenoid bone loss and whether reimplantation is possible or not in anatomical total shoulder arthroplasty [2]. Management of significant glenoid bone loss requires either autogenic or allogenic, morselized or structural bone graft. Iliac crest autograft is used in the revision setting because autograft humeral head is not available. For small, contained glenoid defects, morselized autologous iliac crest bone graft or allograft cancellous chips can be used. Glenoid bone loss that requires structural grafts are those that have unacceptable version or inclination and where significant medialization of the joint line is present. Sources for structural grafts include a tricortical iliac crest autograft and femoral head allograft.

Removal of a glenoid component without reimplantation or bone grafting has been described with some success [3], though this has been shown to be inferior to reimplantation of a glenoid component in terms of pain relief and function [24, 67]. The glenoid can also be managed with a single-stage bone graft with or without reimplantation in anatomic TSA or RSA [19]. Scalise and Iannotti found that all 11 of their patients that underwent bone graft without reimplantation had significant subsidence and resorption though this did not correlate with clinical outcome scores [68]. One study showed that single-stage bone grafting with reimplantation of a glenoid component in three revision TSAs did not require further surgical intervention or show signs of loosening at a mean follow-up of 45 months [69]. However, a recent retrospective multicenter study showed that glenoids with large bone defects treated with bone graft and reimplantation for loosening had a 17 % revision rate due to recurrent loosening [70]. Two-stage reimplantation with bone graft has been reported [71, 72]. The timing of bone graft incorporation and subsequent reimplantation of the glenoid component is unclear, however [73]. Antuna et al. found that three total shoulder arthroplasties that underwent two-stage reimplantation at an average of 20 months after bone graft insertion had satisfactory pain reduction and no evidence of component loosening at a mean of 2.6 years of follow-up [2]. For reverse arthroplasty, there is typically enough bone to place a

baseplate in a revision setting, though bone graft may be needed in some cases [23, 60, 74, 75].

Humeral bone loss

Treatment of proximal humeral loss has included hemiarthroplasty, resection arthroplasty, and most commonly and effectively—a reverse shoulder arthroplasty. Hemiarthroplasty alone has higher failure rates in association with extensive proximal humerus bone loss; therefore, allograft-prosthesis composites have been used to address this issue (Fig. 1). Reports have shown good results using a RSA composite with proximal humeral allograft, though long-term studies are needed to determine the longevity of this construct [20]. Concerns using proximal humeral bone allograft include increased cost, donor-to-host infection, increased operative times, failure of graft incorporation, and graft resorption. A recent prospective study evaluated the use of RSA without the use of proximal humeral allograft in patients with proximal humerus loss [76]. Compared with other studies using allograft, they found better results in ASES scores and active forward flexion. They suggested that addition of allograft to the reverse prosthesis does not offer significant advantages or does not improve clinical or radiographic outcomes.

Infection

Treatment options for periprosthetic joint infection include antibiotic suppression, tissue debridement with retention of prosthesis, resection arthroplasty, single vs. two-stage prosthesis exchange, and arthrodesis [25]. Antibiotic suppression alone typically has high failure rates [77]. It can be considered for severely ill patients and those unwilling to undergo further surgery. Prosthesis retention and debridement can be considered if infection has been detected early, though failure rates can reach up to 50 % [78]. Resection arthroplasty can be reserved for the elderly, severely ill patient where the goal is to mainly relieve pain, as this treatment option can leave the patient with poor shoulder function and motion [79]. Single-stage implant exchange can be considered, though it is not as popular as two-stage exchange, which is based on the management of infected total hip and knee arthroplasties. The prosthesis of antibiotic-loaded acrylic cement (PROSTALAC) implant can be used for the eradication of infection and successful two-stage implantation in shoulder arthroplasty. A retrospective, multicenter study found that infection was eradicated in 82 % of patients using the PROSTALAC implant, while 57 % underwent successful two-stage reimplantation [79]. Ince et al. managed 16 patients with infected shoulder arthroplasties with a single-stage method and found no recurrence of infection [80]. Sperling et al. treated three patients with prosthetic infection using a two-stage method and found no recurrence of infection. They also found that one of the two patients treated with a single-stage exchange had reinfection [81]. Cuff et al. compared outcomes of single vs. two-stage exchange with conversion to a reverse total shoulder arthroplasty and found no difference in outcomes between the two methods. They believed successful eradication of infection between the two methods were a result of the quality of the debridement since RSA was anticipated, and there was little concern for resecting suspicious rotator cuff, capsule, and bone tissue [82].

Positive cultures obtained after revision surgery when preoperative workup for infection is negative have been a focus of recent studies, as guidelines are not clearly defined. Grosso et al. treated patients with unexpected positive intraoperative cultures with a one-stage revision and no postoperative antibiotics and found low reinfection rates (5.9 %) [83]. Another study supported ignoring or monitoring unexpected intraoperative positive cultures of low virulence and negative preoperative workup in healthy patients [84]. Recently, Pottinger et al. found preoperative and intraoperative risk factors that correlate with positive cultures during revision surgery. They included male sex, osteolysis, membrane formation, and cloudy fluid. This information might help guide decision-making in prosthesis removal or retention and the need for immediate antibiotic therapy [85]. A recent study evaluated the role of open biopsy prior to reimplantation in a staged procedure. They found that four out of 18 patients had persistent infection. Reimplantation in these patients was delayed with repeat I&D, antibiotic spacer exchange, and IV antibiotics for 6 weeks until cultures were negative. All patients were free of infection at a 2-year follow-up implicating the possibility of decreasing persistent infection rates using an open biopsy prior to final reimplantation, though a larger, long-termed study is needed. Also, the harmful effects of additional surgery and higher costs seen with this added procedure need to be considered [86].

Nerve injury

Nerve conduction studies and electromyography should be used if a nerve injury is suspected postoperatively. They should be obtained 10–21 days postoperatively because these studies are unable to differentiate between axonal loss vs. demyelination [21••]. Injury as a result of neurapraxia resolves with time; however, surgical exploration of the affected nerve may be considered if no recovery is seen by EMG analysis 3 months postoperatively [41]. The majority of postoperative nerve injury, however, is due to neurapraxia that mainly requires conservative management and close monitoring. Lynch et al. found no nerve injuries requiring surgical exploration in 18 shoulder arthroplasties and with all injuries due to a neurapraxia or first-degree injury that resolved spontaneously [33]. Therefore, in the setting of neurapraxia, surgical intervention is not necessary.

Loosening

The management of loosening is similar to that in the primary setting. First, it is necessary to determine if the patients' symptoms are truly related to loosening. Start-up pain or pain at the extremes of motion is often noted. Second, because a re-revision has significant risk and increasing limited options, an extensive preoperative workup and discussion with the patient is imperative as the results are unpredictable and may only improve patient function in the most limited of circumstances. Serial standardized radiographs should be obtained to assess progression of radiolucent lines and to correlate with clinical symptoms. A bone scan is a valuable tool in assessing loosening along with a diagnostic arthroscopy. Loosening on the glenoid side is easily treated with conversion to a reverse—the key is determining the extent of bone loss preoperatively with a CT scan using 3D reconstruction and assessing intraoperatively after glenoid removal. Management in this setting is discussed above. Humeral loosening is extremely uncommon but is easily managed by increasing the size of a press-fit stem after sufficient reaming or cementing. A stem can also be cemented back into the remaining stable mantle—"tap out, tap in" technique.

Conclusions

Complications after revision shoulder arthroplasty are more frequently seen and more difficult to manage than in the primary setting. Defining the cause of failure is critical but is complicated due to multiple underlying etiologies that are often present. Management depends on patient factors, the type of prosthesis, and available anatomy. Multiple approaches to these complications have been described in the literature, though results are varied and the evidence is limited. Longer-termed studies are needed to assess patient satisfaction, function, and pain relief. Adhering to basic principles of arthroplasty surgery is the key to good decision-making in these difficult cases.

Compliance with Ethics Guidelines

Conflict of Interest Andrew Jawa and Hithem Rahmi have nothing to disclose.

Human and Animal Rights and Informed Consent No human or animal studies performed by the authors.

No human or animal studies performed by the authors.

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References

Papers of particular interest, published recently, have been highlighted as:

- • Of importance
- •• Of major importance

1. Kim SH, Wise BL, Zhang Y, Szabo RM. Increasing incidence of shoulder arthroplasty in the United States. J Bone Joint Surg Am. 2011;93:2249–54. doi:10.2106/JBJS.J.01994.
2. Antuna SA, Sperling JW, Cofield RH, Rowland CM. Glenoid revision surgery after total shoulder arthroplasty. J Shoulder Elbow Surg. 2001;10:217–24. doi:10.1067/mse.2001.113961.
3. Dines JS, Fealy S, Strauss EJ, et al. Outcomes analysis of revision total shoulder replacement. J Bone Joint Surg Am. 2006;88(7):1494–500.
4. Ahmadi S, Lawrence T, Sahota S, Schleck C, Harmsen W, Cofield R, et al. The incidence and risk factors for blood transfusion in revision shoulder arthroplasty: our institution's experience and review of the literature. J Shoulder Elbow Surg. 2014;23:43–8.
5. Saltzman B, Chalmers P, Gupta A, Romeo A, Nicholson G. Complication rates comparing primary with revision reverse total shoulder arthroplasty. J Shoulder Elbow Surg. 2014;23(11):1647-54. doi:10.1016/j.jse.2014.04.015.
6. Miller BS, Joseph TA, Noonan TJ, et al. Rupture of the subscapularis tendon after shoulder arthroplasty: diagnosis, treatment, and outcome. J Shoulder Elbow Surg. 2005;14:492–6.
7. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. J Arthroplast. 1999;14:6.
8. Sanchez-Sotelo J, Sperling JW, Rowland CM, Cofield RH. Instability after shoulder arthroplasty: results of surgical treatment. J Bone Joint Surg Am. 2003;85(4):622–31.
9. Kempton L, Balasubramaniam M, Ankerson E, Wiater M. A radiographic analysis of the effects of prosthesis design on scapular notching following reverse total shoulder arthroplasty. J Shoulder Elb Surg. 2011;20(4):571–6. doi:10.1016/j.jse.2010.08.024.
10. Kowalsky M, Galatz L, Shia D, Steger-May K, Keener J. The relationship between scapular notching and reverse shoulder arthroplasty prosthesis design. J Shoulder Elbow Surg. 2012;21:1430–41.
11. Chalmers P, Rahman Z, Romeo A, Nicholson P. Early dislocation after reverse total shoulder arthroplasty. J Shoulder Elbow Surg. 2014;23:737–44.
12. Edwards TB, Williams MD, Labriola JE, Elkousy HA, Gartsman GM, O'Connor DP. Subscapularis insufficiency and the risk of shoulder dislocation after reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2009;18(6):892–6. doi:10.1016/j.jse.2008.12.013.
13. Boileau P, Melis B, Duperron D, Moineau G, Rumian A, Han Y. Revision surgery of reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2013;22:1359–70.
14. Williams GR, Ianotti JP. Management of periprosthetic fractures: the shoulder. J Arthroplasty. 2002;17(4 suppl 1):14–5.
15. Athwal S, Sperling J, Rispoli D, Cofield R. Periprosthetic humeral fractures during shoulder arthroplasty. J Bone Joint Surg Am. 2009;91:594–603.
16. Campbell J, Moore R, Iannotti J, Norris T, Williams GR. Periprosthetic humeral fractures: Mechanisms of fracture and treatment options. J Shoulder Elbow Surg. 1998;7(4):406–413. ISSN 1058–2746, doi: 10.1016/S1058-2746(98)90033-7. 388–95. doi: 10.1302/0301-620X.86B3.14024.

17.• Throckmorton T, Canale ST, Beaty J. Chapter 12: shoulder and elbow arthroplasty. Campbell's operative orthopedics. Elsevier Health Sciences. 12ed, 2013 (electronic);532–582.
18. Cofield R. Revision and complex shoulder arthroplasty (1st). Philadelphia: Lippincott Williams & Wilkins; 2010. *Retrieved July 12, 2014 from http://www.r2library.com/Resource/Title/078177747X.*
19. Namdari S, Goel D, Romanowski J, Glaser D, Warner JP. Principles of glenoid component design and strategies for managing glenoid bone loss in revision shoulder arthroplasty in the absence of infection and rotator cuff tear. J Shoulder Elbow Surg. 2011;20:1016–24.
20. Chacon A, Virani N, Shannon R, Levy JC, Pupello D, Frankle M. Revision arthroplasty with use of a reverse shoulder prosthesis-allograft composite. J Bone Joint Surg Am. 2009;91:119–27. doi:10.106/JBJS.H.00094.
21.•• Wiater BP, Moravek JE, Wiater JM. The evaluation of the failed shoulder arthroplasty. J Shoulder Elbow Surg. 2014;23:745–58. *This article provides important evaluation and workup information that are specific for managing the failed shoulder arthroplasty. It also overviews common complications and the causes which exhibits to the reader that the cause of a failed shoulder arthroplasty is multifactorial.*
22. Patel D, Young B, Onyekwelu I, Zuckerman J, Kwon Y. Reverse total shoulder arthroplasty for failed shoulder arthroplasty. J Shoulder Elbow Surg. 2012;21:1478–83.
23. Scalise J. Management of glenoid bone loss in revision total shoulder arthroplasty. Tech Should Elbow Surg. 2008;9(2):85–90.
24. Cofield RH, Edgerton BC. Total shoulder arthroplasty: complications and revision surgery. Instr Course Lect. 1990;39:449–62.
25. Bohsali KI, Wirth MA, Rockwood Jr CA. Complications of total shoulder arthroplasty. J Bone Joint Surg Am. 2006;88:2279–92. doi:10.2106/JBJS.F.0012.
26. Mook W, Garrigues G. Diagnosis and management of periprosthetic shoulder infections. J Bone Joint Surg Am. 2014;96:956–65. doi:10.2106/JBJS.M.00402.
27. Sperling J, Hawkins R, Walch G, Zuckerman J. Complications in total shoulder arthroplasty. J Bone Joint Surg Am. 2013;95:563–9.
28. Dodson CC, Craig EV, Cordasco FA, Dines DM, Dines JS, Dicarlo E, et al. Propionibacterium acnes infection after shoulder arthroplasty: a diagnostic challenge. J Shoulder Elbow Surg. 2010;19(2):303–7.
29. McGoldrick E, McElvany M, Butler-Wu S, Pottinger P, Matsen F. Substantial cultures of Propionibacterium can be found in apparently aseptic shoulders revised three years or more after the index arthroplasty. J Shoulder Elbow Surg. 2015;24(1):31-5. doi:10.1016/j.jse.2014.05.008.
30. Levy O, Iyer S, Atoun E, Peter N, Hous N, Cash D, et al. Propionibacterium acnes: an underestimated etiology in the pathogenesis of osteoarthritis? J Shoulder Elbow Surg. 2013;22(4):505–11. doi:10.1016/j.jse.2012.07.007.
31. Sherfey MC, Edwards TB. Cement extrusion causing radial nerve palsy after shoulder arthroplasty: a case report. J Shoulder Elbow Surg. 2009;18:e21–4. doi:10.1016/j.jse.2009.01.006.
32. Nagda S, Rogers K, Sestokas A, Getz C, Ramsey M, Glaser D, et al. Neer award 2005: peripheral nerve function during shoulder arthroplasty using intraoperative nerve monitoring. J Shoulder Elbow Surg. 2007;16:S2–8.
33. Lynch NM, Cofield RH, Silbert PL, Hermann RC. Neurologic complications after total shoulder arthroplasty. J Shoulder Elbow Surg. 1996;5:53–61.
34. Ladermann A, Lubbeke A, Melis B, Stern R, Christofilopoulos P, Bacle G, et al. Prevalence of neurologic lesions after total shoulder arthroplasty. J Bone Joint Surg Am. 2011;93:1288–93. doi:10.2106/JBJS.J.00369.
35. Edwards TB, Labriola J, Stanley R, O'Connor D, Elkousy H, Gartsman G. Radiographic comparison of pegged and keeled glenoid components using modern cementing techniques: a prospective randomized study. J Shoulder Elbow Surg. 2010;19:251–7.
36. Nuttall D, Haines J, Trail I. A study of the micromovement of pegged and keeled glenoid components compared using radiostereometric analysis. J Shoulder Elbow Surg. 2007;16(3S):S65–70.
37. Throckmorton T, Zarkadas P, Sperling J, Cofield R. Pegged versus keeled glenoid components in total shoulder arthroplasty. J Shoulder Elbow Surg. 2010;19:726–33.
38. Mansat P, Briot J, Mansat M, Swider P. Evaluation of the glenoid implant survival using a biomechanical finite element analysis: influence of the implant design, bone properties, and loading location. J Shoulder Elbow Surg. 2007;16:S79–83. doi:10.1016/j.jse.2005.11.010.
39. Lazarus MD, Jensen KL, Southworth C, Matsen 3rd FA. The radiographic evaluation of keeled and pegged glenoid component insertion. J Bone Joint Surg Am. 2002;84:1174–82.
40. Franklin JL, Barrett WP, Jackins SE, Matsen 3rd FA. Glenoid loosening in total shoulder arthroplasty. Association with rotator cuff deficiency. J Arthroplasty. 1988;3:39–46.
41. Torchia ME, Cofield RH, Settergren CR. Total shoulder arthroplasty with the Neer prosthesis: long-term results. J Shoulder Elbow Surg. 1997;6:495–505.
42. Suarez DR, Nerkens W, Valstar ER, Rozing PM, van Keulen F. Interface micromotions increase with less-conforming cementless glenoid components. J Shoulder Elbow Surg. 2012;21:474–82. doi:10.1016/j.jse.2011.03.008.
43. Nagels J, Valstar ER, Stokdijk M, Rozing PM. Patterns of loosening of the glenoid component. J Bone Joint Surg (Br). 2002;84:83–7. doi:10.1302/0301-620X.84B1.11951.
44. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg. 2005;14(1 suppl S):147S–61S.
45. Cil A, Veillette CJ, Sanchez-Sotelo J, Sperling JW, Schleck C, Cofield RH. Revision of the humeral component for aseptic loosening in arthroplasty of the shoulder. J Bone Joint Surg (Br). 2009;91:75–81. doi:10.1302/0301-620X.91B1.21094.
46. Maynou C, Petroff E, Mestdagh H, Dubois HH, Lerue O. Clinical and radiologic outcome of humeral implants in shoulder arthroplasty. Acta Orthop Belg. 1999;65:57–64. *French*.
47. Matsen 3rd FA, Iannotti JP, Rockwood Jr CA. Humeral fixation by press-fitting of a tapered metaphyseal stem: a prospective radiographic study. J Bone Joint Surg Am. 2003;85:304–8.
48. Sanchez-Sotelo J, O'Driscoll SW, Torchia ME, Cofield RH, Rowland CM. Radiographic assessment of cemented humeral components in shoulder arthroplasty. J Shoulder Elbow Surg. 2001;10:526–31.
49. Verborg O, El-Abiad R, Gazielly DF. Long term results of uncemented humeral components in shoulder arthroplasty. J Shoulder Elbow Surg. 2007;16:13–8.
50. Sperling JW, Cofield RH, O'Driscoll SW, Torchia ME, Rowland CM. Radiographic assessment of ingrowth total shoulder arthroplasty. J Shoulder Elbow Surg. 2000;9:507–13.
51. Cuff D, Clark R, Pupello D, Frankle M. Reverse shoulder arthroplasty for the treatment of rotator cuff deficiency: a concise follow-up, at a minimum of five years, of a previous report. J Bone Joint Surg Am. 2008;90(6):1244–51.
52. Melis B, DeFranco M, Ladermann A, Mole D, Favard L, Nerot C, et al. An evaluation of the radiological changes around the Grammont reverse geometry shoulder arthroplasty after eight to 12 years. J Bone Joint Surg (Br). 2011;93:1240–6. doi:10.1302/0301-620X.93B9.25926.
53. Moeckel BH, Altchek DW, Warren RF, et al. Instability of the shoulder after arthroplasty. J Bone Joint Surg Am. 1993;75:492–7.

54. Ankem HK, Blaine TA. Revision shoulder arthroplasty. Tech Shoulder Elbow Surg. 2005;6:189–98.
55. Resch H, Povacz P, Ritter E, et al. Transfer of the pectoralis major muscle for the treatment of irreparable rupture of the subscapularis tendon. J Bone Joint Surg Am. 2000;82:372–82.
56. Elhassan B, Ozbaydar M, Massimini D, Diller D, Higgins L, Warner JJP. Transfer of pectoralis major for the treatment of irreparable tears of subscapularis. J Bone Joint Surg (Br). 2008;90-B: 1059–65.
57. Abboud JA, Anakwenze OA, Hsu J. Soft-tissue management in revision total shoulder arthroplasty. J Am Acad Orthop Surg. 2013;21:23–31.
58. Cheung E, Willis M, Walker M, Clark R, Frankle M. Complications in reverse total shoulder arthroplasty. J Am Acad Orthop Surg. 2011;19(7):439–49.
59. Wall B, Nove-Josserand L, O'Connor DP, Edwards TB, Walch G. Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg Am. 2007;89:1476–85. doi:10.2106/JBJS.F.00666.
60. Klein S, Dunning P, Mulieri P, Pupello D, Downes K, Frankle M. Effects of acquired glenoid bone defects on surgical technique and clinical outcomes in reverse shoulder arthroplasty. J Bone Joint Surg Am. 2010;92(5):1144–54. doi:10.2106/JBJS.I.00778.
61. Van Thiel G, Halloran J, Twigg S, Romeo A, Nicholson G. The vertical humeral osteotomy for stem removal in revision shoulder arthroplasty: results and technique. J Shoulder Elb Surg. 2011;20(8):1248–54. doi:10.1016/j.jse.2010.12.013. *ISSN 1058–2746*.
62. Kumar S, Sperling JW, Haidukewych GH, Cofield RH. Periprosthetic humeral fractures after shoulder arthroplasty. J Bone Joint Surg Am. 2004;86-A(4):680–9.
63. Steinmann SP, Cheung EV. Treatment of periprosthetic humerus fractures associated with shoulder arthroplasty. J Am Acad Orthop Surg. 2008;16:199–207.
64. Hendel MD, Bryan JA, Barsoum WK, Rodriguez EJ, Brems JJ, Evans PJ, et al. Comparison of patient-specific instruments with standard surgical instruments in determining glenoid component position: a randomized prospective clinical trial. J Bone Joint Surg Am. 2012;94:2167–75.
65. Levy J, Everding N, Frankle M, Keppler L. Accuracy of patient-specific guided glenoid baseplate positioning for reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2014;23:1563–7.
66. Walch G, Vezeridis P, Boileau P, Deransart P, Eng M, Chaoui J. Three-dimensional planning and use of patient specific guides improve glenoid component position: an in vitro study. J Shoulder Elbow Surg. 2014. doi:10.1016/j.jse.2014.05.029.
67. Petersen SA, Hawkins RJ. Revision of failed total shoulder arthroplasty. Orthop Clin N Am. 1998;29:519–33.
68. Scalise JJ, Iannotti JP. Bone grafting severe glenoid defects in revision shoulder arthroplasty. Clin Orthop Relat Res. 2008;466: 139–45. doi:10.1007/s11999-007-0065-7.
69. Elhassan B, Ozbaydar M, Higgins LD, Warner JJ. Glenoid reconstruction in revision shoulder arthroplasty. Clin Orthop Relat Res. 2008;466:599–607. doi:10.1007/s11999-007-0108-0.
70. Bonnevialle N, Melis B, Neyton L, Favard L, Mol D, Walch G, et al. Aseptic glenoid loosening or failure in total shoulder arthroplasty: revision with glenoid reimplantation. J Shoulder Elbow Surg. 2013;22:745–51.
71. Iannotti JP, Frangiamore SJ. Fate of large structural allograft for treatment of severe uncontained glenoid bone deficiency. J Shoulder Elbow Surg. 2012;21:765–71. doi:10.1016/j.jse.2011.
72. Cheung EV, Sperling JW, Cofield RH. Revision shoulder arthroplasty for glenoid component loosening. J Shoulder Elbow Surg. 2008;17:371–5. doi:10.1016/j.jse.2007.09.003.
73. Cofield RH. Bone grafting for glenoid bone deficiencies in shoulder arthritis: a review. J Shoulder Elbow Surg. 2007;16:273–81.
74. Norris T, Kelly J, Humphrey CS. Management of glenoid bone defects in revision shoulder arthroplasty: a new application of the reverse total shoulder prosthesis. Tech Should Elbow Surg. 2007;8(1):37–46. doi:10.1097/BTE.0b013e318030d3b7.
75. Holcomb J, Cuff D, Petersen S, Pupello D, Frankle M. Revision reverse shoulder arthroplasty for glenoid baseplate failure after primary reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2009;18(5):717–23.
76. Budge M, Moravek J, Zimel M, Nolan E, Wiater M. Reverse total shoulder arthroplasty for the management of failed shoulder arthroplasty with proximal humeral bone loss: is allograft augmentation necessary? J Shoulder Elbow Surg. 2013;22:739–44.
77. Coste JS, Reig S, Trojani C, Berg M, Walch G, Boileau P. The management of infection in arthroplasty of the shoulder. J Bone Joint Surg (Br). 2004;86(1):65–9.
78. Muh SJ, Streit J, Lenarz C, McCrum C, Wanner J, Shishani Y, et al. Resection arthroplasty for failed shoulder arthroplasty. J Shoulder Elbow Surg. 2013;22:247–52.
79. Jawa A, Shi L, O'Brien T, Wells J, Higgins L, Macy J, et al. Prosthesis of antibiotic-loaded acrylic cement (PROSTALAC) use for the treatment of infection after shoulder arthroplasty. J Bone Joint Surg Am. 2011;93:2001–9. doi:10.2106/JBJS.J.00833.
80. Ince A, Seemann K, Frommelt L, Katzer A, Loehr JF. One-stage exchange shoulder arthroplasty for peri-prosthetic infection. J Bone Joint Surg (Br). 2005;87-B:814–8.
81. Sperling JW, Kozak TK, Hanssen AD, Cofield RH. Infection after shoulder arthroplasty. Clin Orthop Relat Res. 2001;(382):206-16.
82. Cuff DJ, Virani NA, Levy J, et al. The treatment of deep shoulder infection and glenohumeral instability with debridement, reverse shoulder arthroplasty and postoperative antibiotics. J Bone Joint Surg (Br). 2008;90(3):336–42.
83. Grosso M, Sabesan V, Ho J, Ricchetti E, Iannotti J. Reinfection rates after 1-stage revision shoulder arthroplasty for patients with unexpected positive intraoperative cultures. J Shoulder Elbow Surg. 2012;21:754–8.
84. Foruria A, Fox TJ, Sperling J, Cofield R. Clinical meaning of unexpected positive cultures (UPC) in revision shoulder arthroplasty. J Shoulder Elbow Surg. 2013;22:620–7.
85. Pottinger P, Butler-Wu S, Neradilek MB, Merritt A, Bertelsen A, Jette J, et al. Prognostic factors for bacterial cultures positive for Propionibacterium acnes and other organisms in a large series of revision shoulder arthroplasties performed for stiffness, pain, or loosening. J Bone Joint Surg Am. 2012;94(22):2075–83.
86. Zhang A, Feeley B, Schwartz B, Chung T, Ma CB. Management of deep postoperative shoulder infections: is there a role for open biopsy during staged treatment? J Shoulder Elbow Surg. 2015;24(1):e15-20. doi:10.1016/j.jse.2014.04.007.