10 Management of the Failed Anatomic Total Shoulder Arthroplasty

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Introduction

Total shoulder arthroplasty is now the third most commonly performed joint replacement surgery in the United States, behind the hip and knee [1]. Over the past 20 years, there has been a rapid and exponential increase in the number of total shoulder replacements performed. During the 1990s, annual total shoulder arthroplasty rates were less than 10,000 per year; however, in 2011, roughly 67,000 shoulder arthroplasties were performed [1, 2]. The most common indication for an anatomic total shoulder arthroplasty (aTSA) is osteoarthritis of the glenohumeral joint, with an intact rotator cuff and adequate glenoid bone stock [3].

As the prevalence of aTSA continues to increase, a wide spectrum of potential failure mechanisms can be expected to occur. Knowing the common modes of aTSA failure, how they are diagnosed, and how to manage the different failure mechanisms is important not only in managing these complex cases but also preventing them from occurring. This chapter will review the most common mechanisms of aTSA failure, discuss the various diagnostic tools, and review the literature for evidence regarding the best method for revision surgery. Recommendations for treatment including a decision algorithm will be reviewed (Fig. 10.1).

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Mechanisms for Failure

Bohsali et al. have twice performed a systematic review of the literature regarding aTSA complications. Their first review covered publications from 1996 to 2005 and included over 30 studies with more than 2500 patients [5]; their second review of the literature is from 2006 to 2015 and included another 30 studies and over 3300 patients [6]. While the overall rates of complications appear to be declining, component failure, specifically of the glenoid, continues to be a significant problem affecting implant longevity.

Component Failure

The most common mechanism of failure after aTSA is component loosening and wear and fracture [5–7]. Prosthetic loosening accounts for roughly 39% of all complications, affecting 4–6.3% of all shoulders [5, 6]. The mode and cause of component failure is important to understand as these factors will ultimately affect treatment decisions.

Glenoid Component Failure

The glenoid is the most common site of failure (Fig. 10.2) [5, 6]. Glenoid component loosening

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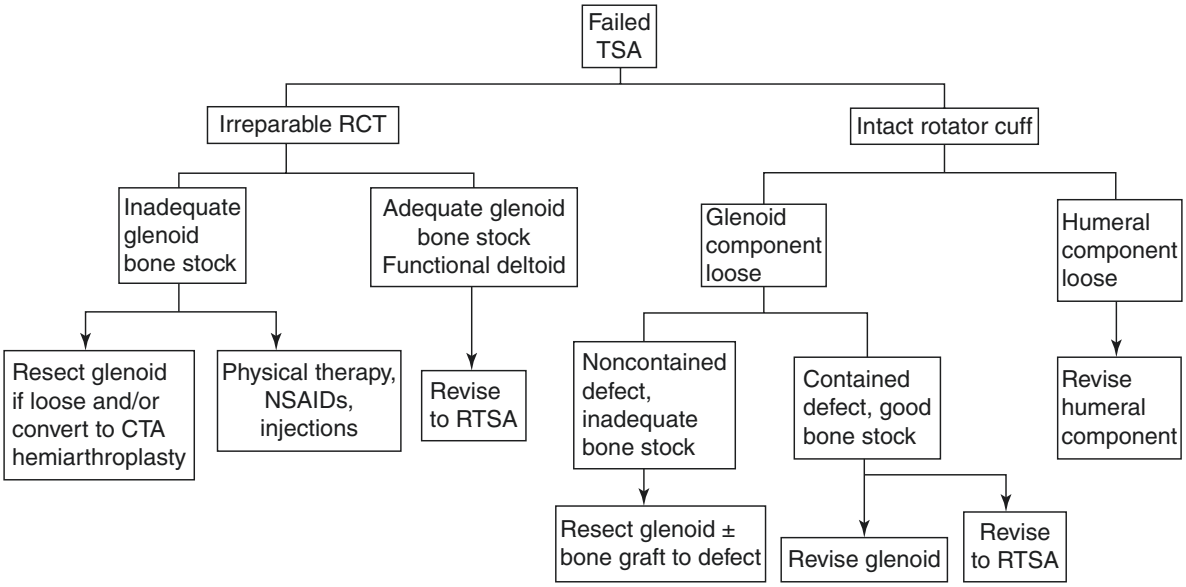

Fig. 10.1 Treatment algorithm for management of the failed anatomic total shoulder arthroplasty without infection or fracture. (Revised and reused with permission from *JAAOS* [4])

was found to account for 32–37.7% of all complications, with 3.9–5.3% of all patients experiencing some degree of loosening [5, 6]. Individual studies have reported glenoid loosening rates as low as 1.1% [8] up to 14% [9]. It is important to note that glenoid loosening may be asymptomatic, not requiring further treatment but only observation. In a systematic review of glenoid failure in aTSA, Papadonikolakis et al. found that the annualized rate of asymptomatic loosening was 7.3%, while symptomatic loosening was lower at only 1.2% and revision even lower at 0.8% [7]. They did not find a correlation between asymptomatic loosening and revision ($r = 0.03$), although symptomatic loosening was correlated with revision ($r = 0.77$) [7]. Thus, asymptomatic loosening may be carefully followed without the need for further workup or treatment. The variability in the literature may be partially explained by a number of design factors that have been linked with glenoid component survival.

There have been numerous reports of inferior outcomes of metal-backed and metal ingrowth glenoids compared to all-polyethylene components due to increased loosening and implant fractures (Fig. 10.3) [10–14]. Rates of loosening of metal-backed components have been reported as 5–42% [10–15]. Fractures of metal-backed implants have been reported to occur in 9.4–21% of cases [11–13]. In addition, biomechanical testing has also favored cemented all-polyethylene components over metal-backed for initial fixation strength and micromotion [16]. Consequently, early designs of true metal-backed glenoids have largely been abandoned [10, 11]. However, the success of ingrowth components in total hip arthroplasty as well as on the humeral side of the shoulder makes the addition of an ingrowth component to the glenoid alluring. Thus, newer designs combining a central ingrowth peg with peripherally cemented pegs attempt to combine the best of both worlds (Comprehensive Total Shoulder System, Zimmer Biomet, Warsaw, IN). Long-term data regarding the success or failure of this implant is currently unavailable.

Another design component that may play a role in longevity is radial mismatch or conformity between the glenoid and humeral head. Decreasing radial mismatch or increasing conformity limits contact stresses at the humeral interface, decreasing glenoid polyethylene wear and improving joint stability; it also decreases the ability for humeral head translation leading to increased contact stresses at the bone-implant interface and the potential for component loosen-

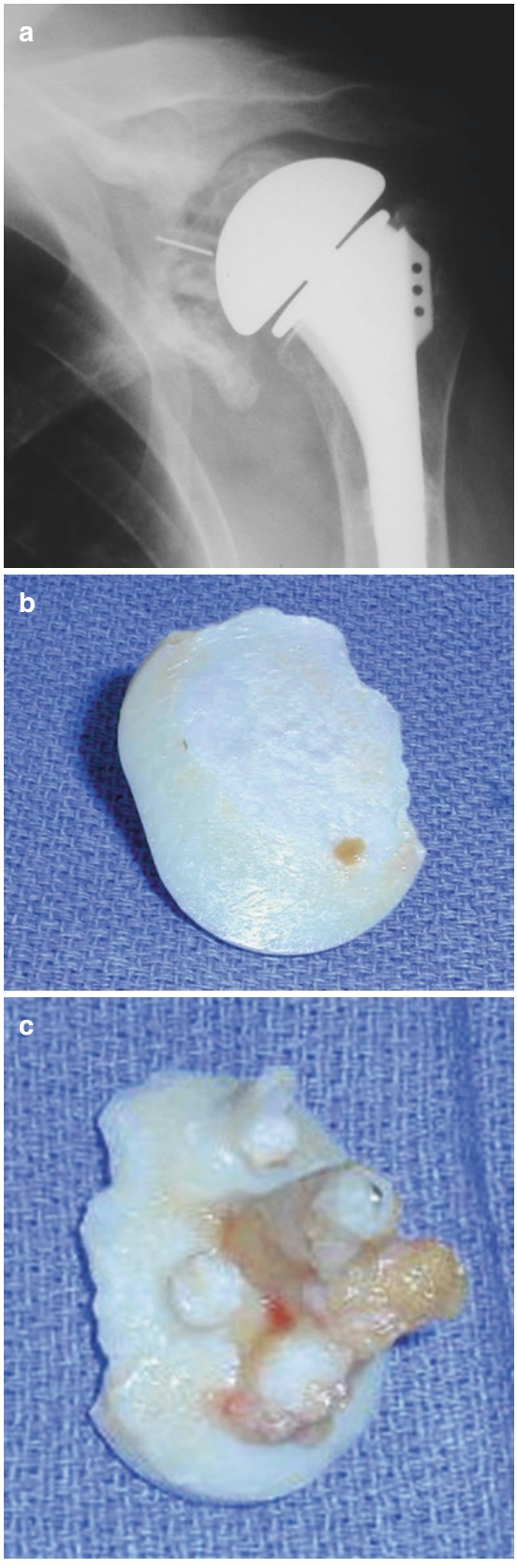

Fig. 10.2 Failed all-polyethylene glenoid. AP radiograph (**a**) demonstrating a loose glenoid component. Glenoid component showing posterior superior wear after removal including articulating surface (**b**) and backside (**c**)

ing [17, 18]. Thus, some radial mismatch, with a glenoid radius of curvature greater than that of the humeral head, may be desirable to balance the risks of wear and instability to the risk of loosening. In a multicenter case series review of 1542 aTSAs using all-polyethylene, cemented, flat-backed glenoids (Tornier Aequalis) followed for 24–110 months, Walch et al. found that glenohumeral radial mismatch between 5.5 and 10 mm resulted in the least amount of radiolucent changes and mismatch of 4.5–7 mm was associated with better active external rotation of the arm at the side [17]. However, a biomechanical study of a cementless, metal-backed, round, posterior-curved, central screw glenoid implant (Multiplex; ESKA, Lübeck, Germany) by Suárez et al. found that increasing mismatch from 0 mm to 6 mm led to significantly increased micromotion at the bone-implant interface. The authors contributed this finding to increased humeral head translation resulting in the rocking-horse phenomenon [18]. While some relative micromotion between the bone and the component of less than 150 μm allows for bone ingrowth in a cementless design, too much is detrimental and may be one reason for early component failure in metal-backed designs [18, 19]. Additional research is needed to understand the optimal radial mismatch for aTSA which will likely affect the method of glenoid fixation.

Currently used cemented glenoids are designed with a keel or a peg on the backside for fixation into the glenoid. This is another area of design debate. Early results suggested that keeled designs were at a higher risk for developing radiolucency and ultimate failure. However, more recent data has shown that mid- to long-term results are equivalent for radiolucencies surrounding the implant and the need for revision [20, 21].

The degree of glenoid component retroversion at implantation may also play a role in long-term survivorship with most authors recommending techniques that restore glenoid version under 10 degrees of retroversion. However, data supporting such a recommendation is unclear. A biomechanical model demonstrated greater than 10° of retroversion dramatically increased eccentric load on the posterior implant

[22]. Clinically, a 2013 study examined 66 aTSAs from 2 to 7 years postoperatively and correlated over 15° of component retroversion with a significant increase in osteolysis around the center peg of a press fit, bone ingrowth design, although this was not related to worse patient outcomes or an increased rate of reoperation [23]. Conversely presented in 2017, researchers using the same glenoid at a different facility compared 21 aTSA glenoids implanted with 15° or greater of retroversion to 50 implanted in less than 15° between 18 and 36 months postoperatively and found no significant difference between groups regarding osteolysis, outcomes, or reoperation [24].

Humeral Component Failure

The humeral component in aTSA loosens infrequently. According to Bohsali et al., the rate of humeral loosening is decreasing from roughly 6.5% of all complications or 1% of all aTSAs in the decade preceding 2005 down to 1.5% or 0.1%, respectively, in the decade up to 2015 [5, 6]. There is limited evidence from a small ($n = 40$

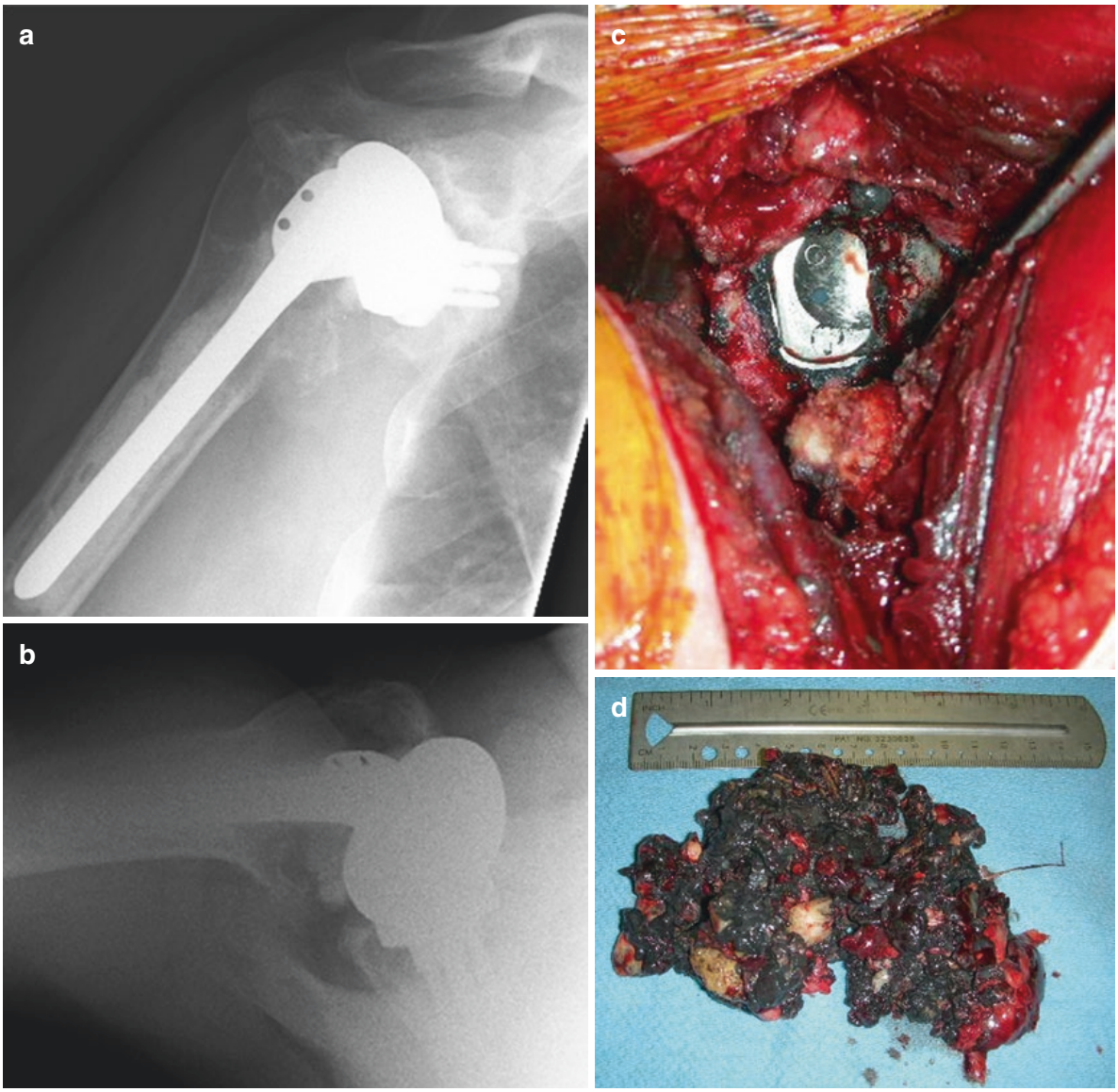

Fig. 10.3 Failed metal-backed glenoid. AP (**a**) and lateral (**b**) radiographs demonstrating a failed glenoid component. Intraoperative photo demonstrating metal debris in situ (**c**) and after debridement (**d**). Glenoid component showing anterior superior wear after removal including articulating surface (**e**) and backside (**f**)

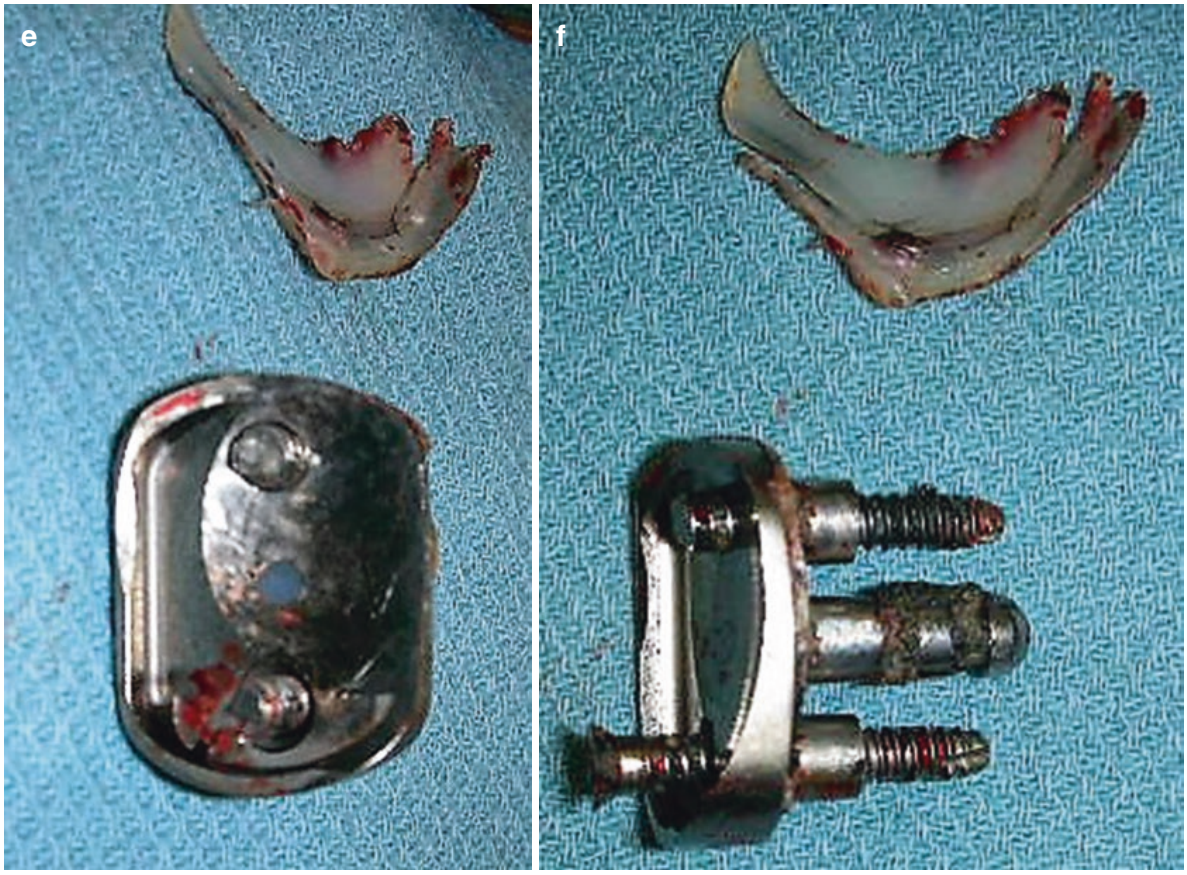

Fig.10. 3 (continued)

aTSAs) level IV study suggesting cemented humeral stems may loosen less frequently than press fit [25]. If loosening occurs, the underlying etiology is an important factor to be addressed during treatment. Causes include glenoid polyethylene wear leading to osteolysis, infection, and fracture [6]. Infection should be ruled out prior to consideration of other etiologies. Improper component positioning or failure to restore anatomic humeral anatomy may be the major source of humeral component failure.

Soft Tissue Dysfunction

Capsular integrity and a competent rotator cuff are critical to the success of aTSA; therefore, soft tissue dysfunction is the second most common cause of aTSA failure [5, 6]. Instability was identified by Bohsali et al. as the second most common aTSA complication, after component failure, albeit with a decreasing incidence from 30% of all complications or 4.9% of all aTSAs down to 10.1% and 1.0% from 1996 to 2015 [5, 6]. Tearing of the rotator cuff has a more stable prevalence, accounting for roughly 7.7–9% of complications (0.9–1.3% of all aTSAs) [5, 6].

The subscapularis tendon is particularly at risk as it is usually taken down to gain access to the joint to perform the procedure and subsequently repaired. Rates of subscapularis failure after aTSA range from 1% to 6% [8, 26] attributing to over half of all rotator cuff dysfunction [5]. Failure of the repair or general subscapularis dysfunction can have devastating consequences to the aTSA patient including anterior instability, pain, internal rotation weakness, and overall poor shoulder function. Such complications have been associated with lengthening procedures of the tendon, an oversized humeral component,

poor tissue quality, and early, excessive postoperative external rotation or resisted internal rotation [6, 26].

The superior rotator cuff musculature, including the supraspinatus and infraspinatus, is also at risk of tearing after aTSA. This may be due to poor tissue quality or continued degeneration, muscular atrophy, superior glenoid tilt, or an oversized humeral head [6]. Tearing of the tendons can lead to superior migration of the humeral head, loss of motion and strength for overhead activities, pain, and poor function.

Posterior capsular insufficiency can result in pain and posterior instability. This is associated with significant glenoid retroversion, which results in stretching of the posterior capsule as the humeral head rests in a subluxated position [27]. Correcting the glenoid retroversion and balancing of the soft tissue tension, such as using posterior capsulorrhaphy, at the index procedure can help decrease this risk [28, 29].

Fractures

The third most common cause for aTSA failure is fracture. Periprosthetic fractures have also shown a declining incidence from 11% to 6.7% of all complications, now affecting 0.69% of all aTSA patients down from 1.8% [5, 6]. Higher Charlson comorbidity index scores and female sex have been associated with higher risk for periprosthetic fractures [30]. Fracture is often associated with loosening of the stem, and stem loosening is associated with infection. Therefore periprosthetic fractures should be considered for an infection workup prior to revision.

Infection

Infection is a devastating complication after aTSA. The rate of infection has been reported to range from 0.7% to 2.3% [5, 8, 9, 15, 31–33]. Bohsali et al.'s reviews found that rate of infection has remained stable at 4.6–4.9% of all complications or 0.51–0.7% of all aTSAs [5, 6]. A National Inpatient Sample report by Padegimas et al. found a similar incidence of 0.98% [33]. Infections significantly increase the financial burden for hospital systems and payors [33]. The risk of infection is increased with nutritional deficits, male sex, drug abuse, blood transfusion, and increasing body mass index [33, 34].

Miscellaneous

Other reasons for failed aTSA are much less common. Poor range of motion can result from arthrofibrosis or excessive heterotopic ossification (HO). Studies looking at HO after aTSA have reported rates of 15–45% [35, 36]. Although seen on imaging with some frequency, HO rarely affects the glenohumeral joint or results in functional deficits [36, 37]. Another source of failure is nerve injury. This may manifest in the form of complex regional pain syndrome, pain of unknown origin, or muscle weakness with atrophy including deltoid dysfunction. Nerve injury may affect 0.63–0.8% of all shoulders undergoing aTSA [5, 6].

Treatment Options and Outcomes for the Failed Anatomic Total Shoulder

Treatment of a failed aTSA is dependent on the mode of failure. As previously discussed, failure can be a result of rotator cuff insufficiency, component malpositioning, fracture, infection, and soft tissue dysfunction, all of which can result in pain, instability, and loosening. Therefore, revision surgery, if indicated, must take into account the underlying pathology in order to optimize outcomes.

Treatment for Component Failure

The glenoid component is the most common site of failure. Indications for revision surgery include

pain or mechanical symptoms of the shoulder due to glenohumeral joint instability or a loose glenoid component with subsidence and/or tilting. While intrinsic factors such as radial mismatch between the glenoid and humeral component and normal wear resulting in osteolysis can contribute to loosening, other causes such as rotator cuff insufficiency and infection should be investigated prior to revision surgery [38, 39]. Rotator cuff insufficiency, joint instability, and infection can be the primary cause or occur in conjunction with glenoid loosening. Addressing not just the primary cause but the associated pathologies is of utmost importance in gaining a satisfactory outcome.

Glenoid Reimplantation Versus Hemiarthroplasty (Bone Grafting and Glenoid Removal)

A failed glenoid may require surgical removal with revision to another aTSA (glenoid reimplantation), conversion to a hemiarthroplasty, or conversion to a reverse total shoulder arthroplasty (rTSA). Reimplantation with a new glenoid is a good option provided that there is adequate bone stock of the glenoid vault. This can be completed as a single- or two-stage revision with or without bone grafting. Conversion to a hemiarthroplasty can likewise be done with or without bone grafting. Revision to rTSA will be discussed in a later section of this chapter.

Regardless of the chosen revision option, first the failed glenoid must be removed. In the setting of a loose glenoid, this is typically quite simple to perform. Any broken pieces should be removed, and a synovectomy to remove wear particles is frequently necessary. Should revision surgery be undertaken for glenoid malpositioning or polyethylene wear in the setting of good glenoid fixation, removal may be more intensive. It is helpful to know the manufacturer of the implanted system, as many have developed specialized tools to simplify component removal. For an all-polyethylene glenoid (Fig. 10.4), removal begins by cutting the implant into quadrants with a straight, sharp osteotome. Each quadrant can then be disassociated from the bony glenoid with the use of a curved osteotome between the bone and the cement or between the cement and the glenoid. This will leave the pegs or keel from the glenoid as well as cement remaining in the bone. For a trabecular metal ingrowth component, a similar strategy is typically successful. For a true metal-backed glenoid, start with screw removal followed by the use of a small, curved or flexible osteotome between the implant and bone in a progressive fashion. Confirm that you have appropriate screw drivers available as these are usually flat-headed screws to lie behind the poly. Depending on the revision planned, it is only necessary to remove as much or as little of the remaining implant and cement as is necessary for fixation of the new implant. Care should be taken to preserve as much bone stock as possible. It is often possible to drill, burr, or ream through the remaining polyethylene, cement, or trabecular metal only where it is impeding placement of a new component. Care should be taken to collect any debris when using this technique. This can be done by placing lap sponges or a viscous substance, such as sterile ultrasound gel, to protect the peripheral tissues and collect the debris. Sponges can then be removed, while gel can be suctioned. Should conversion to a hemiarthroplasty be done, it may be necessary to perform a more thorough cement removal to prevent its articulation with a metal humeral head and subsequent metal wear. If there is concern for infection, all foreign bodies should be removed which typically requires the use of small curettes and osteotomes (e.g., ¼″) to dislodge cement and remaining polyethylene components from the glenoid. This may lead to significantly greater bone loss.

After implant removal and debridement, there are several reconstructive techniques available to restore anatomic version and offset to allow for appropriate tensioning of the rotator cuff muscles and improve function and stability in the aTSA. Eccentric reaming can help restore anatomic version of the glenoid if correction of only 10–15° is required [40]. Further correction could narrow and compromise the glenoid vault and subsequent glenoid screw or peg fixation while also decreasing offset by further medializing the joint line [41]. While correction of glenoid version to neutral has been advocated as the appro-

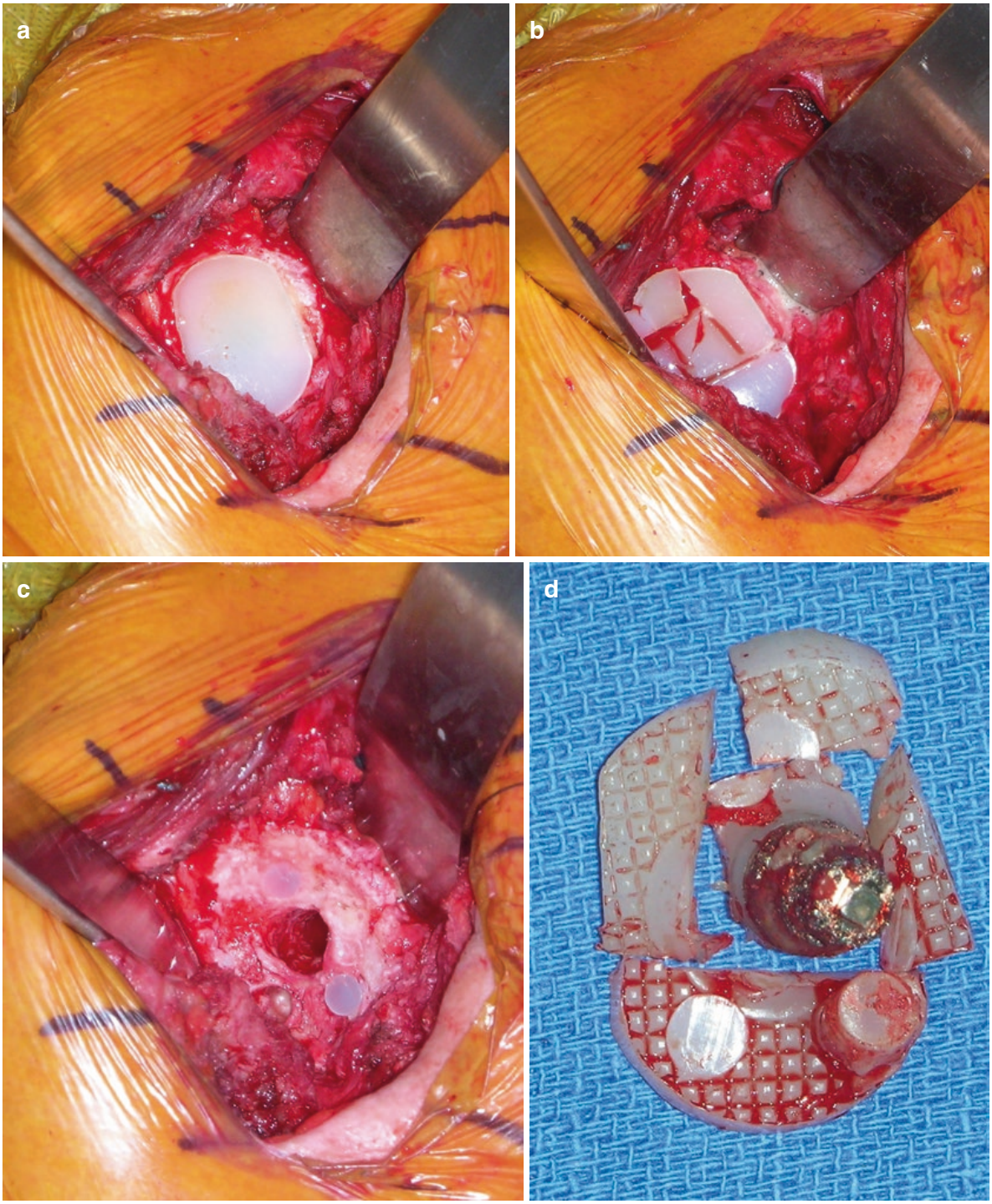

Fig. 10.4 Removal of a well-fixed all-polyethylene glenoid including glenoid exposure (**a**) and in vivo breakdown (**b**). After glenoid removal, if polyethylene pegs are well fixed, they may be left in place (**c**) and drilled through for fixation of a new reverse glenoid baseplate as was done in this case. The glenoid component is thus removed in parts (**d**)

priate technique, more recent literature suggests that retroversion may not be as detrimental as previously thought [24]. Regardless, in the setting of revision surgery, where bone loss is often encountered and the glenoid has already been reamed during the primary procedure, an attempt to neutralize version via reaming alone may further complicate matters. Loss of support from

violation of the subchondral plate may lead to instability of the glenoid component and ultimate failure [5]. Therefore, care must be taken to preserve as much bone stock as possible. Bone graft, cancellous or corticocancellous, can be used to fill bony defects and provide structural support for the new glenoid. Alternatively, posterior augments can also be used to compensate for bone loss and help restore anatomic version and offset with minimal reaming [42]. When indicated, eccentric reaming may be preferable over a posteriorly augmented glenoid because of the possibility of accelerated implant loosening when comparing angled augmented glenoid implants to a neutral version glenoid component [43]. The new glenoid is often cemented and should use third-generation cementation techniques [44]. A previous pegged glenoid can be replaced with a new pegged or keeled implant depending on the condition of the peg holes, while a failed keeled component is revised to another keeled glenoid [41]. It is desirable to have at least 50–60% of the new glenoid supported by native glenoid [45].

Hemiarthroplasty with bone graft is an option if the glenoid has significant bone loss [46, 47]. It can be the definitive treatment for an appropriately selected patient or serve as the first stage in a two-stage reimplantation. If the cortical walls of the glenoid vault are relatively intact, allograft cancellous chips can be used to fill any void [46]. Alternatively, an autogenous iliac crest bone graft or femoral head structural allograft can be used to augment the glenoid and prevent medialization of the joint line by positioning the cortical surface laterally to provide structural support [46, 47]. The graft can be impacted with cancellous bone packed behind and around the graft or secured with cortical screws. Care should be taken to position and direct the screws away from the lateral surface to prevent metal-on-metal wear in the setting of conversion to hemiarthroplasty and to allow adequate space for glenoid reimplantation if planned. Complications include failure of graft incorporation, graft resorption, and subsidence. Subsidence was observed to be more severe with structural graft versus cancellous graft which may be a result of the stiffer structural graft in combination with a lack of cortical rim and underlying bony support from the native glenoid [46]. Complete loss of the glenoid vault down to or beyond the scapular confluence (intersection of the coracoid, spine, and body) may preclude the ability to bone graft and require conversion to a hemiarthroplasty.

Hemiarthroplasty without bone grafting should be reserved as a salvage option when addressing a failed glenoid that cannot be reconstructed [41]. During this procedure the glenoid can be reamed (ream and run technique) to a slightly larger radius of curvature than the humeral head implant to allow a more congruent joint surface. However, in cases of significant bone loss, this may be difficult if not impossible to perform and result only in further medialization of the joint line. In these instances, only glenoid removal may be possible.

Outcomes for Glenoid Reimplantation Versus Hemiarthroplasty with Bone Grafting

Glenoid loosening treated with either reimplantation of a new glenoid component or glenoid removal and bone grafting without glenoid reimplantation was previously investigated by Cheung et al. (2008) [48]. There was significant improvement in pain for both groups. Pain improvement occurred in 73% of the new glenoid group ($N = 33$) versus 54% in the bone grafting group ($N = 35$). This difference did not reach significance ($p = 0.65$). Average follow-up was 3.8 years for the new glenoid group and 6.2 years in the bone grafting group. There was also no significant difference in range of motion when comparing preoperative to postoperative exam except for forward elevation in the group treated with a new glenoid ($p = 0.0387$). The rate of survival-free reoperation at 5 years was 91% in the new glenoid group versus 78% in the bone grafting, which was not found to be significant ($p = 0.3$). Interestingly, 20 shoulders had a late positive culture, with *Propionibacterium acnes* being the most common organism isolated. The authors concluded that revision surgery for a loose glenoid component using reimplantation or bone grafting can often provide pain relief and patient satisfaction. Deutsch et al. found that reimplanta-

tion of a new glenoid resulted in statistically significant pain relief and increased external rotation compared to conversion to hemiarthroplasty [45]. These authors noted that rotator cuff integrity and glenohumeral joint stability were important components to improve outcomes in terms of motion, function, and pain [45].

Aibinder et al. reported outcomes for glenoid loosening revision surgery comparing the same techniques (reimplantation of a new glenoid component ($N = 20$) versus glenoid removal and bone grafting without glenoid reimplantation ($N = 11$)) with a mean follow-up of 8.3 years [49]. The rate of survival-free reoperation at 10 years was 79% in the new glenoid group versus 84% in the bone grafting group, which was not found to be significant ($p = 0.5$). There was a trend for reoperation in patients with preoperative instability (5/8). Pain relief occurred in 26/31 shoulders regardless of treatment type. Active elevation and external rotation improved in both groups. The authors concluded that reimplantation of a glenoid component is reasonable in an active patient with a sufficient glenoid bone stock, an intact rotator cuff, and a stable glenohumeral articulation. If a new glenoid cannot be secured, conversion to a hemiarthroplasty is also reasonable (Fig. 10.5).

Treatment of the Failed Metal-Backed Glenoid

For a modular metal-backed glenoid with wear or disassociation of the polyethylene component, poly exchange may be possible. For such a scenario, preoperative planning is of utmost importance. The treating surgeon will need to know the manufacturer and exact version of the patient's current implants in order to determine surgical technique for exchange as well as new component availability. Cheung et al. (2007) reported their results on 12 shoulders (11 Smith & Nephew Richards, Memphis, TN; 1 Kirschner Medical, Fair Lawn, NJ) that underwent component exchange prior to 2002. Only four shoulders had a satisfactory result including the only two patients with an intact rotator cuff and stable shoulder. For a successful modular component revision, the integrity of the rotator cuff and glenohumeral stability are of prime importance [50].

Treatment for Soft Tissue Dysfunction

Subscapularis Tendon Repair and Reconstruction

The subscapularis tendon is most susceptible to injury as previously discussed. Treatment options are determined by the chronicity of the tear. For acute injuries, early repair with gentle mobilization is the best treatment option if there is quality tendon present [26]. For chronic tears or poor tendon quality, augmentation has been described [26, 51–54].

Pectoralis major tendon transfer has been described with limited success. Deprey attempted such a reconstruction while also decreasing the humeral head size to allow subscapularis repair with limited functional gains ([52] as cited in [51]). Elhassan et al. also reported poor functional outcome scores in patients after pectoralis major tendon transfer for chronic subscapularis insufficiency after aTSA [53]. Patients with preoperative anterior subluxation were associated with even worse outcomes. This may be due to the difference in vector of the pectoralis major tendon, which is an anterior chest wall structure, versus the vector of the subscapularis as a posterior chest wall structure. As a result, the pectoralis major tendon transfer may act as a static buttress to improve stability rather than a dynamic constraint that can also improve function [53].

The use of a static bone Achilles tendon allograft has also been described to achieve stability [26]. Moeckel et al. treated 7 patients with anterior instability after shoulder replacement [54]. All were treated with primary repair; 3 required a second revision surgery using Achilles tendon allograft. Stability was eventually achieved for all shoulders, although functional outcomes were not reported. Thus, given the lack of reliable outcomes, subscapularis reconstruction should only be considered if the patient is symptomatic and unwilling or unable to undergo the more reliable procedure, conversion to rTSA. Prevention, with meticulous repair and soft tissue handling of the subscapularis tendon during the index procedure, is imperative.

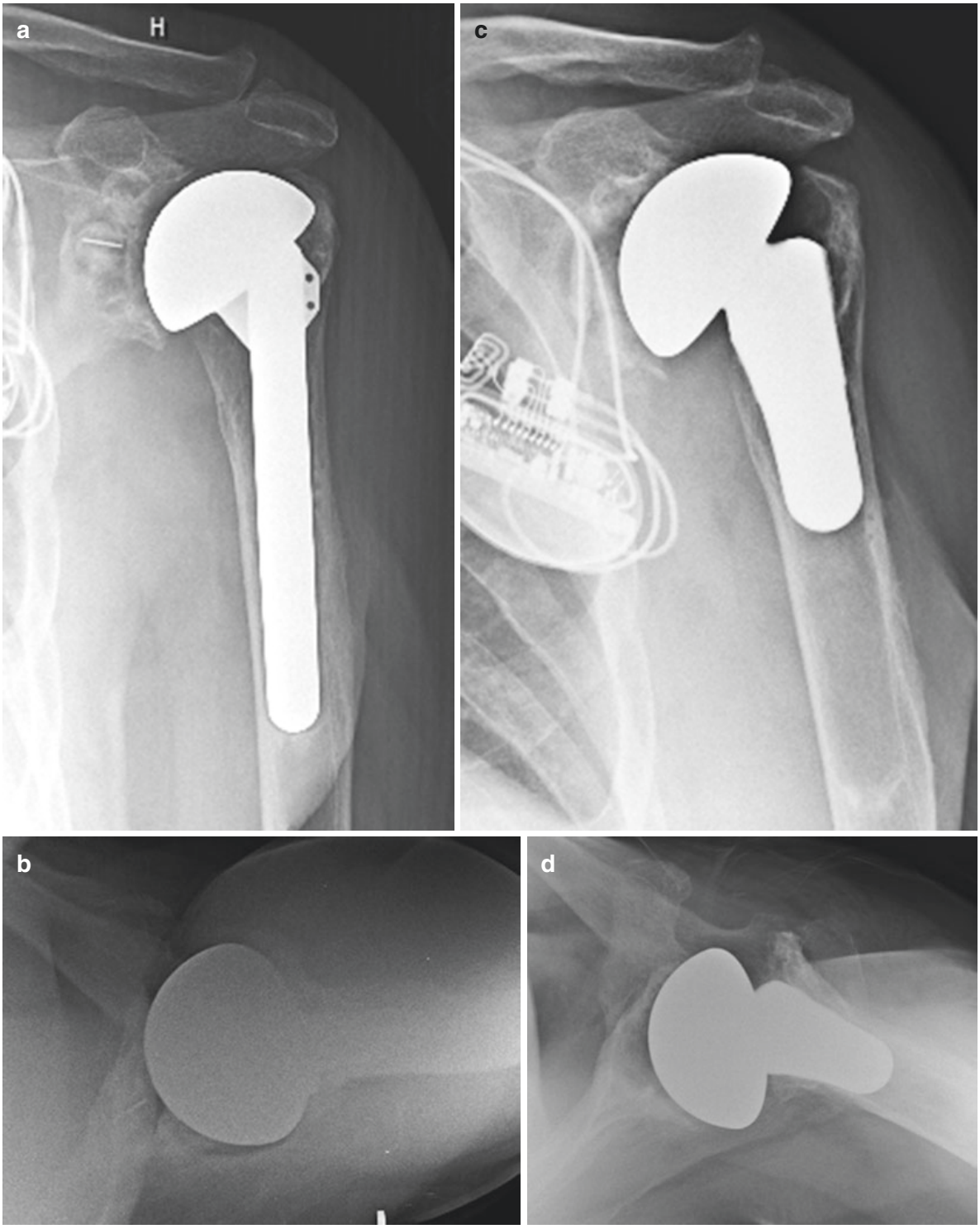

Fig. 10.5 A failed aTSA due to glenoid wear and loosening as seen on AP (**a**) and lateral (**b**) radiographs. The patient had an intact rotator cuff and wished to continue manual labor activities. Therefore, the patient was converted to a hemiarthroplasty as seen on AP (**c**) and lateral (**d**) radiographs

Posterosuperior Rotator Cuff Repair

Supraspinatus and infraspinatus tendon tears can result in weakness in forward elevation and external rotation. Massive disruption of the superior rotator cuff will lead to superior humeral head migration and is more likely to be treated surgically given the associated loss in shoulder function. Initially, conservative

treatment should be utilized for minimal symptoms. Primary open rotator cuff repair was reported by Hattrup et al. with only 4/18 considered successful [55]. Pain relief was reliable after repair but restoration of active motion was poor. As a result, the authors recommended careful repair of the rotator cuff during the index arthroplasty and appropriate postoperative therapy to prevent future tears. Early repair did not improve functional results.

Instability

Instability of a failed aTSA can occur anteriorly or posteriorly and is typically due to soft tissue imbalance or component malposition [56, 57]. Superior instability is usually a result of massive tear of the posterosuperior rotator cuff as previously discussed. Component positioning should always be evaluated, and strong consideration for revision should be made if malpositioning is present. Treatment with surgical revision and maintenance of an anatomic design may result in only modest success. Sanchez-Sotelo et al. reported restoration of stability in only 9 of 32 unstable aTSAs or hemiarthroplasties (with an unsatisfactory Neer rating in 23) treated with revision aTSA or hemiarthroplasty for component loosening, component malposition, and/or soft tissue dysfunction [57].

Treatment and Outcomes for Anterior Instability

The most common causes for anterior instability after an aTSA are subscapularis rupture or insufficiency and excessive anteversion of the humeral and/or glenoid components. As previously discussed, revision surgery for chronic subscapularis insufficiency provides poor results. Unfortunately, results are still poor when an aTSA with anterior instability is revised to another aTSA. Sanchez-Sotelo et al. reported results of 19 aTSAs presenting with anterior instability treated with subscapularis repair and component revision with head exchange [57]. Only 5 of the 19 shoulders were stable on follow-up. Ahrens et al. reported similarly poor results where revision surgery consisted of pectoralis major tendon transfer and component revision ([58] as cited by [51]). Approximately half (17/35) of the shoulders had recurrent instability. Three of the shoulders underwent subsequent revision to a rTSA and achieved stability. These results are likely confounded by subscapularis insufficiency. Isolated component malpositioning with an intact subscapularis may have led to improved outcomes with component revision; however evidence-based studies are not available at this time.

Treatment and Outcomes for Posterior Instability

One potential cause of posterior instability is retroversion of the glenoid component. A preoperative biconcave or dysplastic glenoid (Walch classification B2, B3, C) may be a predisposing factor for posterior instability secondary to retroverted glenoid placement during the primary procedure [56]. One theory to address posterior instability due to glenoid retroversion is through isolated revision of the humeral component to a relatively more anteverted position, creating a more combined anteversion. However, this method was brought into question by a cadaveric model that failed to show a significant difference in shoulder stability when a humeral head in anatomic version was compared to one in 15° of relative anteversion on a glenoid implanted at 15° of retroversion [59]. Alternatively, creating anterior offset of the humeral component has also been proposed to address posterior instability and shows promise. In a cadaveric model, researchers demonstrated that anterior offset of the humeral head resulted in an increased resistance to posterior humeral head translation, shifted joint contact pressures anteriorly, and increased joint contact [60]. Subsequent 3D finite analysis confirmed these findings at increasing degrees of glenoid retroversion [61]. These outcomes provide a potential rationale for using such a technique during revision of aTSA for instability with a retroverted glenoid component and intact rotator cuff.

Other causes of posterior instability include posterior capsular laxity or deficiency. Concomitant posterior capsulorrhaphy with primary aTSA is one method recommended to prevent instability [62]. However, there is limited literature, with inconsistent results, regarding the use of this technique during revision of

aTSA for posterior instability. Sanchez-Sotelo et al. showed modest results in 8 of 14 posteriorly unstable aTSAs treated with such a technique including posterior capsular plication and case-based component revision [57]. Ahrens et al. reported a series of 29 shoulders treated similarly: 15 achieved good results and 4 were revised to an rTSA with good stability ([58] as cited by [51]). Gee et al. reported a case of arthroscopic posterior capsulorrhaphy in a patient presenting with atraumatic posterior instability after aTSA using two suture anchors to imbricate the posterior capsule; the patient had no further symptoms of instability or pain at 2-year follow-up [63].

Treatment for Fracture

Periprosthetic Humerus Fracture

Treatment of periprosthetic fracture is determined by the fracture location, displacement, and stability of the component. The Wright and Cofield classification may help guide treatment. Type A fractures occur near the tip of the humeral stem and extend proximally. Type B fractures occur near the tip of the stem and extend distally. Type C fractures are located distal to the stem [51]. A thorough history should be performed to determine if any preexisting pathology may affect surgical management, such as infection, component loosening, symptomatic osteolysis, or rotator cuff dysfunction.

Non-operative treatment is indicated for minimally or non-displaced fractures with a well-fixed stem or patients with significant medical comorbidities precluding surgery. Criteria for closed treatment are defined as less than 30° of varus/valgus angulation, 20° of flexion/extension, 20° of rotation, and 3 cm of shortening. Typically, type C fractures with a well-fixed component can be considered for closed treatment. A well-fixed type B fracture can undergo a trial of non-operative treatment; however these fractures are at high risk for failure. One study reported that 4 of 5 well-fixed prostheses with type B fractures initially treated closed eventually required surgery [64]. Close follow-up is important for all fractures to ensure that alignment is maintained in the fracture brace or orthosis. Loss of alignment, intolerance to bracing, failure to achieve fracture union within 3 months, and signs of stem subsidence or loosening are indications for surgical management.

Surgical Management

Type A Fractures Type A fractures with a loose stem should be treated with revision to a long stem implant. The tip of the stem should bypass the fracture by 2 to 3 cortical diameters, if possible [64, 65]. Cortical strut allograft can be used if more bony support is required. The fracture should be treated with AO principles and techniques when possible, with the goal of achieving compression and stability at the fracture site. Fixation can be achieved using cerclage wires alone [66] or in combination with plate and screws. Variable angled unicortical screws can be used proximally in conjunction with cerclage cables to obtain fixation around the stem. As for all fractures, a locking plate should be strongly considered in osteoporotic bone.

Treatment of type A fractures with a well-fixed stem is controversial with concern that a well-fixed stem on radiographs may actually be loose. Fractures with a well-fixed stem and acceptable alignment can be treated closed. Displaced fractures can be treated with open reduction internal fixation (ORIF). However, Steinmann and Cheung recommended using the treatment algorithm of a loose stem even if the stem appears well fixed if there is substantial overlap of the fracture and humeral stem in conjunction with fracture displacement greater than 2 mm and 20° of angulation in any plane [67].

Type B Fractures Treatment of type B fractures with a loose stem is treated similarly to type A fractures. A proximally coated long stem implant can be used. Cementation of the distal canal can be considered to improve fixation at the tip of the long stem revision prosthesis. Care should be taken to avoid extrusion of cement.

Treatment for type B fractures with a well-fixed stem can be considered for closed treatment, although is considered at high risk for failure [64]. Surgical fixation involves ORIF using cerclage wires and plates with screws [68]. Allograft strut and bone graft can be used as needed.

Type C Fractures Treatment of type C fractures with a loose stem is less common with loosening likely present prior to injury. As previously mentioned, obtaining a good history is important to elicit any symptoms suggestive of preexisting loosening. A single-stage revision with ORIF and conversion to a long stem is reasonable for a loose stem with sufficient distal bone. However, a staged procedure with ORIF followed by stem revision can be considered to allow fracture healing and reconstitution of the distal bone stock.

Surgical management of type C fractures with a well-fixed stem involves isolated ORIF using AO principles.

Outcomes of Periprosthetic Humerus Fractures

Kumar et al. reported the largest series (16) investigating postoperative humerus fractures, 10 of which received surgical intervention [64]. The average time to union was 278 days for the fracture fixation group versus 180 days for the non-operative group. As a result, they recommended a trial of closed treatment of fractures with a well-fixed stem, and non-operative criterion is met. Despite achieving union for all fractures, 9 of 16 reported unsatisfactory results using the Neer criteria. Loss of motion was determined to be most responsible for the dissatisfaction. Similarly Wright and Cofield found 6 of 9 patients (5 treated closed, 2 treated with ORIF using screws and cerclage wires, 2 treated with revision arthroplasty) to have unsatisfactory results despite obtaining union in 8 patients [69] The average time to union was 4–6 months. In contrast, Worland et al. reported a series of 6 patients (1 closed treatment, 1 ORIF, 1 revision arthroplasty), all of which healed with satisfactory results [65]. The average time to union was 3.3 months. Overall, complication rates were high including hardware failure, delayed union, frozen shoulder, infection, and axillary and radial nerve neuropraxia [68].

Treatment for Infection

There is minimal data specific to the treatment of an infected aTSA. Evidence-based treatment strategies are often adopted from the total hip and knee arthroplasty literature. As a result, chronicity of infection and time from index surgery often determine the surgical management of a confirmed periprosthetic shoulder infection. Current literature does not show any significant differences in successful eradication when treating an acute (within 3 months of index surgery), subacute (between 3 and 12 months from index surgery), or late infection (presenting over 1 year from index surgery) [70]. Differentiating an acute versus chronic infection is difficult and dependent on patient reliability and history.

Surgical Management

Segawa et al. proposed a classification based on clinical presentation in total knee arthroplasty that has been extrapolated to guide surgical treatment of periprosthetic shoulder infection [71, 72].

Type I Periprosthetic Shoulder Infections

Type I infections have a positive culture after revision surgery for aseptic loosening in a shoulder without previous diagnosis of infection. These patients are treated with an organism-specific antibiotic only [71]. There is limited data regarding recommendations for length of antibiotic treatment.

Type II Periprosthetic Shoulder Infections

Type II infections occur within 30 days of the primary procedure. Immediate surgical debridement and prosthetic retention are preferred in addition to postoperative intravenous antibiotics.

Type III Periprosthetic Shoulder Infections

Type III infections are acute hematogenous infections in a well-functioning joint greater than 30 days from index surgery. Treatment is controversial and determined by surgeon preference.

Options include surgical debridement with prosthetic retention, single stage prosthesis revision, or two-stage revision starting with hardware removal and placement of an antibiotic cement spacer followed by reimplantation surgery. Explantation can be difficult with a well-fixed implant and requires a meticulous approach. Small flexible osteotomes should be available for implant extraction and cement removal. Humeral osteotomy, similar to an extended trochanteric osteotomy, can be used to safely remove a well-fixed humeral component followed by fixation using a cerclage technique and possible allograft augmentation [73]. One-stage revision is reasonable with a well fixed prosthesis and low virulence organism [74]. A course of postoperative intravenous antibiotics with a multidisciplinary approach (infectious disease and microbiology) is recommended regardless of prosthetic retention or removal [75].

In the setting of two-stage revision, reimplantation should be delayed for 8–12 weeks. Inflammatory markers should return to normal after an antibiotic holiday. Reimplantation can be more difficult secondary to loss of bone stock and difficult exposure from soft tissue contractures and scarring.

Type IV Periprosthetic Shoulder Infections

Type IV infections are chronic and should be treated with surgical debridement, two-stage revision, and a course of intravenous antibiotics. Surgical debridement should be thorough with removal of all necrotic tissue and cement present. Reimplantation, if possible, should may be attempted after completion of the antibiotic course presuming inflammatory markers return to normal following an antibiotic holiday.

Resection arthroplasty may be indicated if there is massive bone loss, continued infection, or the patient is medically unable to tolerate prosthesis reimplantation.

Outcomes for Surgical Treatment of Infections

A recent systematic review evaluated the outcomes for surgical treatment of periprosthetic infections after shoulder arthroplasty [70]. Greater than 90% success rate for eradicating infection was found for resection arthroplasty (93.3%), antibiotic spacer-only (90.3%), single-stage excluding unexpected positive cultures (91.7%), and two-stage revisions (93.8%). Success decreased to 90.1% for single-stage revision surgery when a subset of patients who required revision surgery were included. These patients were presumed to have an aseptic etiology during the time of revision but then had an unexpected positive intraoperative culture. Irrigation and debridement with implant retention had only a 69% success rate. However, implant retention also resulted in the best postoperative range of motion in all planes (abduction, forward elevation, and external rotation). Single-stage revisions provided statistically greater abduction when compared to two-stage revisions. Single-stage revisions also demonstrated a trend ($p = 0.06$) for higher constant scores compared to two-stage revisions [70]. A more recent study reported less encouraging results with 19 shoulders that underwent two-stage revision that resulted in a recurrent infection rate of 26% (5/19). Noninfectious complication rates were 16% (3/19), which included aseptic loosening and fracture. The authors noted that these patients had multiple operations prior to their two-stage revision [76].

Revision to Reverse Total Shoulder Arthroplasty

Successful treatment of a failed aTSA hinges upon restoring stability to the glenohumeral joint such that muscular forces can restore motion and strength to the shoulder. Many of the previously mentioned treatment challenges can be addressed with conversion to a rTSA (Fig. 10.6).

In the case of aTSA failure due to glenoid component loosening, fracture, or wear, there is typically inadequate bone stock to support reimplantation of an anatomic, cemented glenoid. Doing so risks a significant decrease in offset, which can result in instability, early failure, repeat loosening, and poor outcomes. For an rTSA glenoid baseplate, bony fixation is achieved through ingrowth rather than cementing, a degree of medialization is well tolerated and preferred in

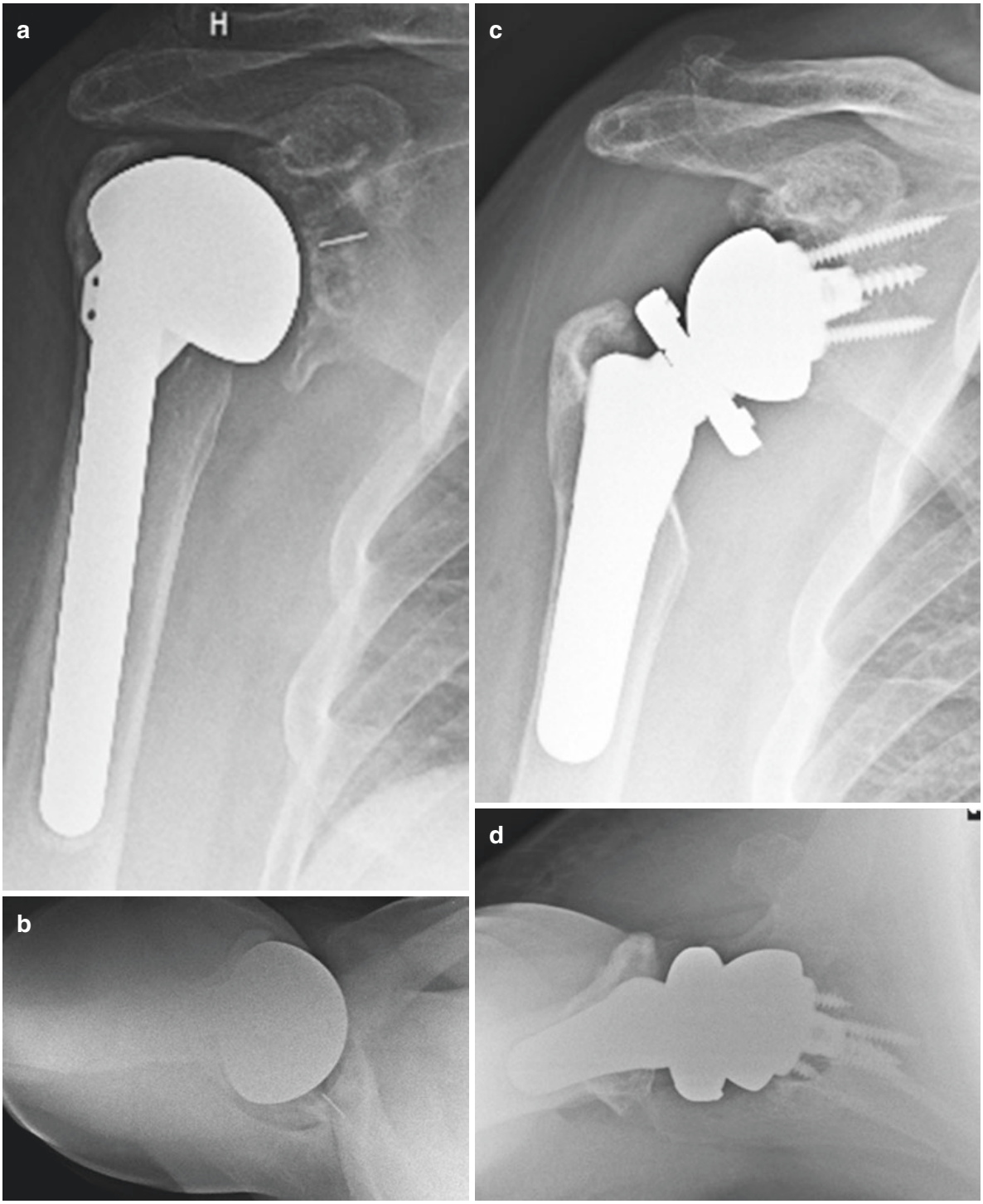

Fig. 10.6 A failed aTSA due to glenoid wear and loosening of both the humeral and glenoid components as seen on AP (**a**) and lateral (**b**) radiographs. Due to glenoid bone loss, the patient was converted to an rTSA as seen on AP (**c**) and lateral (**d**) radiographs

some designs, and placement can vary based on glenoid characteristics. Secure early fixation and optimal placement for bone ingrowth can be chosen by directing the central screw to the best remaining bone stock at the scapular spine, base of the coracoid, or scapular pillar [19]. According to a biomechanical study, as little as 50% bony support of the baseplate is adequate for secure

early fixation [77]. One must often be willing to accept a baseplate in a superior position to allow for secure fixation. Implant systems that allow a degree of glenosphere eccentricity on the baseplate can then be used to move the articulation inferiorly.

In the senior author's experience (JMW), a minimum of 20 mm of glenoid depth prior to reaming is needed for stability of the central post/screw on most implant systems. This can be determined with the use of a small diameter drill bit and depth gauge or Lindemann drill to sound the bone and find the optimal location for post-placement and backside bony coverage. If bony support is felt to be questionable, either bone grafting or augmentation may be utilized. In the setting of revision aTSA to rTSA, bone grafting can be accomplished with iliac crest autograft or femoral head allograft fitted to the medial aspect of the baseplate and secured with an extended central post or screw in addition to peripheral screws. Specialized designs exist to simplify the technique (BIO-RSA, Tornier, Wright; Memphis, TN). This should lateralize the joint line to a more anatomic position. Variability in the literature exists as to whether or not doing so improves clinical outcomes such as external rotation after primary rTSA [78–80]. Alternatively, metal-augmented baseplates are being developed for use and have shown early promise [81, 82].

Despite these options, glenoid bone stock may still be insufficient to support a baseplate. Complete loss of the walls of the glenoid vault with a large, cavitary, unconfined defect can be encountered. In these instances, it is unlikely that any form of bone grafting or augmentation will allow for secure baseplate fixation. A hemiarthroplasty, possibly with an extended articulating surface, may be the patient's only option in these cases.

Soft tissue dysfunction due to rotator cuff tear, with anterior or superior instability, is a standard operative indication for primary rTSA [83]. Outcomes of primary reverse total shoulder have been shown to be independent of subscapularis integrity [84]. It is also indicated in the setting of failed aTSA for these diagnoses as well as in the setting of posterior subluxation or instability from glenoid deformity. The versatility of a reverse baseplate location on the remaining glenoid, as described above, makes it an excellent option in these settings.

Conversion to a reverse arthroplasty requires not only revision of the glenoid component but also of the humeral component. Older designs may necessitate complete humerus removal and exchange if no modular component exists to switch from a humeral head to a humeral tray and polyethylene. Newer modular designs may allow for a simple exchange presuming the humeral stem is well-positioned and not loose [85]. However, if the shoulder is unable to be reduced without excessive force, the humeral stem may need to be removed such that the humerus can be cut down and stem seated in a lower position to allow reduction. Alternately, some implant systems allow the tray to be placed in an eccentric position which may allow reduction.

Outcomes for Revision to Reverse Total Shoulder Arthroplasty

Melis reported an 86% satisfaction rate from a multicenter cohort study for patients undergoing aTSA revision to rTSA for glenoid loosening [86]. Eight of 37 shoulders required a reoperation for complications including glenosphere loosening, anterior instability, and humeral subsidence. Repeat revision to a hemiarthroplasty or resection arthroplasty was performed in 2 patients. Shields and Wiater performed a retrospective study of their patient population undergoing conversion of an aTSA to rTSA for component loosening or rotator cuff tear compared to a cohort undergoing primary rTSA [83]. Both groups had significant improvements in VAS pain scores and ASES functional scores that were not significantly different. However, patient satisfaction (74% versus 90%) and subjective shoulder values (63 ± 30 versus 79 ± 21) were significantly lower for the revision group. The authors conjectured that this difference in subjective outcomes despite similar functional outcomes may be a result of patient expectation and psychology associated with revision surgery in addition to reoperation patients in

the revision group. In addition to lower subjective scores, complications were also significantly higher in the revision group (31%) versus the primary cohort (13%). Given the high rate of complications associated with aTSA revision to rTSA, patients should be counseled on postoperative complications and high rates of reoperation when converting a failed aTSA to rTSA.

Conclusion

Management of the failed aTSA is one of the most challenging problems a shoulder surgeon will face. Causes of failure are complex and often multifactorial including component failure, soft tissue dysfunction, fracture, infection, and a variety of miscellaneous issues. Treatment must address not only the primary cause of failure but any additional complications or underlying issues. Recognition is the first step to success. Understanding the needs of the individual patient and appropriately tailoring treatment is the second step. While revision to another aTSA has been described, results are poor if the patient is not carefully selected or the shoulder unsuitable for such a revision, meaning unstable or sporting a torn rotator cuff. Most patients that require revision of a failed aTSA will ultimately undergo conversion surgery to either a hemiarthroplasty or an rTSA. Hemiarthroplasty may reliably reduce pain but may not offer a highly functional outcome depending on the patient's needs and desires. Reverse TSA has the potential to successfully address a wide range of etiologies. However, complication rates are high. Regardless of the management choice, both the patient and the surgeon should be prepared for the range of potential outcomes and complications.

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