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Diagnosis and Management of the Infected Shoulder Arthroplasty

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Introduction

The number of total shoulder arthroplasties performed in the United States is rapidly increasing [1, 2]. A recent review of the NIS database estimated that the number of primary shoulder arthroplasties in the United States more than tripled from 2002 to 2011 [2]. During this same time period, the incidence of infection after primary total shoulder arthroplasty (TSA) remained constant, at just under 1% [2]. This number is consistent with other published data showing the infection rate in primary TSA ranging from 0.7% to 1.8%, accounting for approximately 3–5% of all complications after unconstrained TSA [3, 4]. Infection in the setting of reverse total shoulder arthroplasty (RSA) has been reported to be higher than that for unconstrained TSA. Zumstein et al. performed a systematic review of 21 studies (782 patients) and reported a deep infection rate of 3.8% (2.9% primary, 5.8% revision) at a minimum 2-year follow-up after RSA [5]. In 2011, Trappey et al. found a 3% infection rate after RSA in their cohort of 284 patients [6]. Recently, Walch et al. have challenged these findings, noting a decreased infection rate (0.9% versus 4%) when comparing a recent series of RSA cases to a series from the early use of the prosthesis [7]. They conclude that surgeon experience likely plays a key role in this complication. Though the incidence of infection after shoulder arthroplasty remains low, periprosthetic joint infection (PJI) continues to be a burden to patients, surgeons, hospitals, and the healthcare system, with a median institutional cost of $17,163.57 for each shoulder PJI hospitalization, based on estimates from the Hospital Cost Utilization Project (HCUP) data from 2011 [2].

Despite an increasing number of infected shoulder arthroplasties, the diagnosis and management of this problem is still evolving. Recent literature has demonstrated that the most common cultured organisms are *Propionibacterium acnes* (*P. acnes*) and *coagulase-negative Staphylococcus species.* The indolent nature of these organisms makes clinical presentation subtle and diagnosis elusive. Standard diagnostic testing used for hip and knee PJI do not perform as well in the shoulder, most commonly from lower sensitivity of these tests in the shoulder. After diagnosis is made, there is a lack of evidence available to guide decision-making on optimal treatment. This chapter will review the diagnosis and management of the infected shoulder arthroplasty, particularly indolent infections, including patient evaluation and diagnostic strategies, along with current management options and outcomes.

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Diagnosis

History and Physical Examination

Infections in total joint arthroplasty (TJA) are often classified by chronicity as acute (less than 3 months after surgery), subacute (3–12 months after surgery), and late/chronic (more than 1 year after surgery) [3, 8]. Infections caused by non-virulent organisms, such as *P. acnes*, are typically present since the time of primary arthroplasty but are often chronic by the time of diagnosis, as the paucity of clinical signs of infection leads to a delay in diagnosis. For this reason, the surgeon needs to be vigilant and maintain a high index of suspicion for infection in any patient with persistent pain after shoulder arthroplasty.

A thorough history and focused shoulder examination is critical to diagnosing infection after shoulder arthroplasty. The physician should inquire about fever, warmth at the incision, erythema, and purulent drainage from the wound. Most often, however, these symptoms are not present with shoulder infections given the indolent nature of the infecting organisms, particularly *P. acnes.* Key portions of the history when evaluating a potential PJI of the shoulder include duration of pain relief before recurrence of symptoms, postoperative stiffness, hematoma formation, postoperative wound drainage, history of multiple previous shoulder surgeries, use of antibiotics, and smoking history. Hematoma formation after shoulder arthroplasty, particularly if necessitating an irrigation and debridement procedure, has been associated with the development of positive cultures and subsequent deep infection [9]. Smoking history has also been directly associated with shoulder PJI. A recent study evaluated infection risk associated with smoking and found a hazard ratio of 7.27 for patients who had smoked within 1 month of their shoulder arthroplasty. Interestingly, patients who were former smokers (no smoking within 1 month of surgery) still had a 4.5 times greater chance of developing a postoperative deep infection following shoulder arthroplasty when compared to non-smokers [10]. Werthel et al. also recently found that patients who had a non-arthroplasty shoulder surgery prior to shoulder arthroplasty developed deep infections twice as often [11]. Finally, the overall health of the patient is also important, as periprosthetic shoulder infections occur more commonly in patients with chronic systemic diseases and those who cannot mount an immune response. A recent study by Bala and colleagues showed that patients who were HIV positive had a higher risk of developing a shoulder PJI compared to healthy controls [12].

Pain is the most common complaint of patients with an infected shoulder arthroplasty [13–16]. Determining the onset, duration, and frequency may help determine the chronicity of the infection. The pattern of pain may also help distinguish infection from other aseptic causes of pain such as loosening or instability. Patients may describe pain that is present in the immediate postoperative period and does not improve over time in the setting of shoulder PJI, or they may have a period of initial improvement after surgery followed by the development of pain. While loosening or instability typically causes pain with activity only, patients with infection often report pain at rest or describe it as constant but worse with activity. Excessive stiffness can be associated with pain and with infection [14, 15]. Patients may note inability to regain motion after surgery, and this stiffness can increase symptoms of pain.

Physical examination of the shoulder should start with inspection of the patient's prior incision(s). Overtly concerning signs include redness or cellulitis, swelling, purulent drainage, or a chronic sinus tract. Most often the incision(s) will look benign in a low-grade or subclinical infection. Specifically, *P. acnes* infections are very rarely associated with purulent drainage [17–19] or abnormal-appearing wounds but occasionally present with a non-blanching, erythematous rash. Signs of muscle atrophy, particularly in the deltoid and rotator cuff muscles, should also be noted as possible evidence of another problem, such as a rotator cuff tear or nerve injury. Tenderness can be noted when palpating about the shoulder, particularly along the glenohumeral joint line. Range of motion of the

shoulder will demonstrate signs of stiffness, which is typically present in all planes. End-range pain is usually associated with loss of motion. Discrepancies in passive and active range of motion should also be determined and can raise concern for an associated rotator cuff or nerve injury. Strength testing of the shoulder will also bring out evidence of a possible rotator cuff problem or nerve injury.

Diagnostic Testing

Currently, there is no single diagnostic test that is reliable enough to detect shoulder PJI, particularly in the setting of an indolent infection. The diagnosis can be challenging in this setting and must utilize a combination of pre- and intraoperative laboratory tests and imaging modalities. The most common preoperative tests that are obtained include serum markers; paticularly white blood cell (WBC) count, C-reactive protein (CRP), and Erythrocyte sedimentation rate (ESR); joint aspiration, plain radiographs, advanced imaging studies [3]. Recent studies have also looked into the utility of synovial markers, including leukocyte esterase, alpha-defensin, and several cytokines in the diagnosis of shoulder PJI [20–24]. Intraoperatively, if revision surgery is indicated, multiple tissue specimens should be obtained from around the prosthetic components for analysis by both microbiology and pathology.

In the early postoperative period, serum CRP and ESR may normally be elevated rendering them less useful. It is not known when these levels normalize after shoulder arthroplasty; however, in the hip and knee literature, it has been reported that CRP typically peaks on the second postoperative day and normalizes within 2 weeks of an uncomplicated surgery [25, 26]. ESR declines more slowly, and one or both may remain elevated for longer periods in patient with inflammatory arthropathy, such as rheumatoid arthritis. In this subset of patients with inflammatory disease, it is important to consider a rise from baseline, as they often have a CRP/ESR that is elevated above normal limits even in the absence of surgery or infection. Though serum CRP and ESR have been shown to have a high negative predictive value in hip and knee arthroplasty, this cannot be extrapolated to the shoulder. Both tests are inconsistently elevated in the presence of shoulder PJI, likely due to the indolent nature of the most commonly isolated organisms. Topolski et al. and Kelly and Hobgood demonstrated a large percentage of patients with positive intraoperative cultures at revision surgery that had negative preoperative serum markers, including WBC count, ESR, and CRP [27, 28]. Nodzo and colleagues also recently found that serum ESR and CRP elevation was significantly less common in the setting of *P. acnes*-associated shoulder PJI compared to *P. acnes* hip and knee PJI at the same institution [29]. Serum interleukin-6 (IL-6) has received attention in hip and knee PJI due to increased sensitivity and specificity in diagnosis [30] and has subsequently been evaluated in the shoulder. Villacis et al. prospectively evaluated the utility of serum IL-6 levels and showed that there was no difference in IL-6 between infected and non-infected shoulder arthroplasties. They also showed that the sensitivity, specificity, positive predictive value, negative predictive value, and accuracy were 14%, 95%, 67%, 61%, and 62%, respectively [21]. This compares to sensitivity, specificity, positive predictive value, negative predictive value, and accuracy for serum WBC of 7%, 95%, 50%, 59%, and 59%; for ESR of 21%, 65%, 30%, 54%, and 47%; and for CRP of 0%, 95%, 0%, 57%, and 56%, in the same study. Similarly, in the study by Grosso et al., the sensitivity of serum IL-6 was 12%, and the specificity was 93%, making it less sensitive than ESR and CRP (42% and 46%, respectively) in their series [23]. While an elevated serum ESR, CRP, or WBC should raise concern for a potential PJI of the shoulder, a negative result does not rule out an infected arthroplasty. Based on the lack of additional benefit, serum IL-6 is not a recommended tool for the work-up of shoulder PJI.

A variety of imaging studies have been used to aid in the diagnosis of shoulder PJI. Plain radiographs are always obtained when evaluating a painful shoulder arthroplasty and can often

be helpful in the diagnosis of shoulder PJI. In particular, it is important to examine the images for any signs of radiolucency around that implant or gross loosening of one or both components that could be attributable to infection. Of particular concern is implant radiolucencies or loosening that develops in the early years after the index procedure. Periosteal new bone formation can also be seen in the setting of shoulder PJI. CT can confirm evidence of implant radiolucencies or loosening seen on plain radiographs or detect more subtle signs of these findings that cannot be seen on plain radiographs, particularly when using metal artifact reduction techniques. Ultrasound and MRI have been used for detection of a fluid collection if there is clinical concern. Ultrasound may be a better test as the presence of a significant metal artifact may make MRI difficult to interpret [14]. PET scan has been shown to be helpful in diagnosis of PJI of the hip [14, 31], but no literature exists evaluating its use for detection of shoulder PJI. A technetium Tc-99 bone scan and indium In-111-labeled WBC scan have been used for diagnosis of hip and knee PJI and may be useful in a limited role for the shoulder if other testing is equivocal [26].

Aspiration can be attempted as another part of the diagnostic work-up of shoulder PJI. The volume of fluid aspirated, however, can often preclude performing multiple synovial fluid tests due to less synovial fluid production with indolent shoulder PJI when compared to the knee and hip. Successful shoulder aspiration rates have been reported from 38.8% to 56% [8, 32]. If aspiration is successful, it is critical that the patient is not currently on any antibiotics that may cause a false negative result and that the aspirate is cultured for an appropriate length of time. Patients should be off of antibiotics for a minimum of 2–3 weeks to obtain an accurate culture [26], and a culture should be held anaerobically for 14 days to increase the likelihood of detecting less virulent bacteria, like *P. acnes*, although incubation times of up to 21 days have been reported for *P. acnes* [14, 33–35]. Synovial fluid WBC with differential from the aspirate has been shown to be useful in the diagnosis of hip and knee PJI; however, no literature with regard to cut-off levels for shoulder PJI is currently available.

Several recent studies have evaluated the utility of synovial fluid biomarkers for diagnosing PJI of the shoulder. Synovial IL-6 was prospectively evaluated by Frangiamore et al. in a study of 35 painful shoulder arthroplasties undergoing revision surgery. Using receiver operating characteristic curve analysis, a cutoff value of 359.3 pg/mL led to sensitivity, specificity, and positive and negative likelihood ratios of 87%, 90%, 8.45, and 0.15, respectively. Seven patients with negative preoperative work-up were later diagnosed with infection based on multiple positive intraoperative cultures, and the synovial IL-6 level was elevated in five of them, with a mean level of 1400 pg/mL. Levels were also significantly elevated in patients with *P. acnes*-positive cultures [22]. In a similarly modeled study, Frangiamore et al. evaluated synovial α-defensin (Synovasure, CD Diagnostics) in 33 painful shoulder arthroplasties undergoing revision surgery. Sensitivity, specificity, and positive and negative likelihood ratios were 63%, 95%, 12.1, and 0.38, respectively, and α-defensin was significantly elevated in patients with *P. acnes*-positive cultures and moderately correlated with the number of positive intraoperative cultures [36]. Nearly all culture-positive cases in these two studies were *P. acnes*, coagulase-negative S*taphylococcus*, or another indolent organism. Following these single synovial biomarker studies, Frangiamore et al. prospectively evaluated a multiplex assay of 9 synovial fluid cytokines in 75 cases of revision shoulder arthroplasty. When evaluating the individual cytokines in this study, the authors found that synovial IL-1B, IL-6, IL-8, and IL-10 showed the best combined sensitivity and specificity for predicting infection (Table 12.1). However, cytokine combinations were also assessed for diagnostic performance, and a 3-cytokine statistical model using IL-6, TNF-alpha, and IL-2 was found to have better diagnostic test characteristics than any individual synovial cytokine alone (Table 12.1). A nomogram was developed from the model to predict likelihood of infection for a given patient based on their specific cytokine levels [24].

Table 12.1 Synovial fluid cytokine diagnostic test characteristics for infection

Cytokine	AUC[a]	Optimal cut-off[a] (pg/mL)	Sensitivity	Specificity	PPV	NPV	LR+	LR−
IL-6	0.87	453.6	0.82	0.87	0.79	0.89	6.4	0.20
GM-CSF	0.70	1.5	0.54	0.85	0.68	0.75	3.6	0.55
IFN-γ	0.69	4.9	0.60	0.80	0.62	0.78	3.0	0.50
IL-1β	0.80	3.6	0.71	0.87	0.77	0.84	5.6	0.33
IL-12	0.60	6.0	0.36	0.94	0.77	0.71	5.6	0.69
IL-2	0.70	1.6	0.54	0.87	0.71	0.76	4.2	0.53
IL-8	0.78	1502.4	0.71	0.79	0.67	0.82	3.4	0.36
IL-10	0.76	28.1	0.72	0.82	0.69	0.84	4.0	0.34
TNF-α	0.60	4.5	0.92	0.33	0.43	0.88	1.4	0.24
Combined[b]	0.87	0.4	0.80	0.93	0.87	0.89	12.0	0.21

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+ positive, − negative, *AUC* area under the curve, *GM-CSF* granulocyte-macrophage colony-stimulating factor, *IFN* interferon, *IL* interleukin, *LR* likelihood ratio, *NPV* negative predictive value, *PPV* positive predictive value, *TNF* tumor necrosis factor

[a]AUC and optimal cutoff were determined using receiver operating characteristics curves. Sensitivity, specificity, PPV, NPV, LR+, LR− were determined from the receiver operating characteristic curve analysis

[b]Represents the diagnostic test characteristics of the combined 3-cytokine (IL-6, TNF-α, IL-2) model found to have the optimal predictive power

Leukocyte esterase is another synovial fluid diagnostic test that has shown promising results in hip and knee PJI [37, 38]. However, Nelson et al. evaluated its utility in the shoulder and showed sensitivity, specificity, and positive and negative predictive values of only 30%, 67%, 43%, and 83%. In addition, aspirates that contain blood must be centrifuged prior to leukocyte esterase testing, and 29% of the time, even after centrifuging, the aspirate was too bloody for analysis [20]. The authors did not recommend routine use of this test in the shoulder.

If work-up of a painful shoulder arthroplasty is negative for infection but there is no other indication for revision surgery and the concern for PJI remains high, arthroscopic tissue biopsy may be considered. Multiple tissue samples can be taken from around the components, as well as from the joint capsule, for culture and other causes of pain can also be evaluated, including component loosening and rotator cuff deficiency. Dilisio et al. retrospectively evaluated 19 patients with painful shoulder arthroplasties who underwent arthroscopic biopsy prior to revision surgery, 7 (41%) of which grew *P. acnes*. The sensitivity, specificity, and positive and negative predictive values were all 100%, and all arthroscopic cultures matched with cultures taken during the revision surgery [39]

If a patient is taken to the operating room for revision surgery, intraoperative frozen sections and cultures should be obtained. It is important, as described previously, that the patient be off antibiotics for 2–3 weeks prior to surgery. Historically, an intraoperative gram stain was used to determine if bacteria were present at the time of revision; however, its value has been called into question [40–42], and its routine use is no longer recommended. Appropriate cultures should be sent and incubated for an adequate length of time, including aerobic and anaerobic cultures (incubate up to 21 days), fungal (4 weeks), and mycobacterium (8 weeks) [14]. As noted above, we recommend holding cultures anaerobically for 14 days to increase the likelihood of detecting less virulent bacteria, as the most commonly cultured organisms during revision shoulder arthroplasty are *P. acnes* and *coagulase-negative Staphylococcus* species in recent studies [22, 24, 36]. Intraoperative cultures have been reported to be negative in otherwise clinically confirmed cases of infected shoulder arthroplasty in some earlier studies [8, 15, 43], which is likely due to insufficient tissue samples, inadequate culture length, or remaining on or failing to discontinue antibiotics early enough before surgery. Recommendations from recent literature are to obtain 4–5 tissue specimens for culture at

the time of revision surgery [35, 44]. Tissue samples should ideally be taken from the joint capsule, from the prosthesis-bone interface around both the humeral and glenoid components, and from the intramedullary canal of the humerus. Some of this tissue should also be sent for histology. Intraoperative frozen section is another important diagnostic test for infection, with a criterion of more than five polymorphonuclear leukocytes (PMNs) per high-power field (400x) typically considered positive for PJI in hip and knee arthroplasty [8, 14, 27, 28, 45]. However, this threshold may not be sensitive enough for detecting indolent bacteria in the shoulder, with a recent study investigating the use of alternate criteria. Grosso et al. evaluated 45 patients who underwent frozen section histology during revision shoulder arthroplasty, including 18 *P. acnes* infections and 12 infections from other organisms. Using a standard threshold of 5 PMNs per high-power field, the sensitivity was 50% for *P. acnes* infections and 67% for other infections, while the specificity was 100%. Using a new threshold of 10 PMNs total in the 5 densest high-power fields, the sensitivity for *P. acnes* infections improved to 72% and for other infections improved to 75%, while the specificity remained 100% [46].

Implant sonication fluid culture has also been evaluated with the hopes of improving diagnostic accuracy by culturing the biofilms from explanted prosthetic components [34]. Piper et al. showed that sonication fluid culture significantly improved sensitivity for diagnosis of shoulder PJI from 54.5% to 66.7%, when compared to periprosthetic tissue culture. However, this sensitivity still remained relatively low for culture, and a more recent study by Grosso et al. found no additional benefit to sonication cultures over standard intraoperative cultures for diagnosing shoulder PJI [47]. Based on the results of these two studies, and the increased laboratory support needed to perform this test, implant sonication is not used routinely for diagnosis of shoulder PJI at our institution.

Currently there is no clinical practice guideline available for the work-up and diagnosis and no agreed-upon diagnostic criteria for PJI of the shoulder. The Musculoskeletal Infection Society (MSIS) has defined consensus criteria for PJI of the hip and knee but acknowledged that in low-grade infections, which predominate in the shoulder, several of these criteria may not be routinely met [48, 49] (Table 12.2). In our practice, serum ESR and CRP are obtained in the painful shoulder arthroplasty, and joint aspiration is attempted. If the synovial fluid sample is a large enough volume to send for multiple tests, synovial alpha-defensin and synovial WBC with differential can also be obtained. At the time of surgery, intraoperative tissue specimens and another synovial fluid sample should be obtained and sent for culture and frozen section histology. Frozen sections may help guide decision-making on performing a one- versus two-stage revision, with positive frozen sections a potential indicator of a more aggressive infection that requires two-stage revision. We routinely obtain four to five tissue specimens for culture during revision shoulder arthroplasty from the joint capsule and periprosthetic humeral and glenoid tissue and hold each for aerobic and anaerobic culture for a period of 14 days.

Table 12.2 Definition of periprosthetic joint infection according to the 2013 International Consensus Group

PJI is present when one of the major criteria exists or three out of five minor criteria exist	
Major criteria	Two positive periprosthetic cultures with phenotypically identical organisms, *or*
	A sinus tract communicating with the joint, *or*
Minor criteria	1. Elevated serum C-reactive protein (CRP) *and* erythrocyte sedimentation rate (ESR)
	2. Elevated synovial fluid white blood cell (WBC) count *or* ++change on leukocyte esterase test strip
	3. Elevated synovial fluid polymorphonuclear neutrophil percentage (PMN%)
	4. Positive histological analysis of periprosthetic tissue
	5. A single positive culture

Used with permission from Parvizi and Gehrke [49]
Declaration: The consensus group wishes to state that PJI may be present without meeting these criteria, specifically in the case of less virulent organisms (e.g., *Propionibacterium acnes*). Thus, the clinicians are urged to exercise their judgment and clinical acumen in reaching the diagnosis of PJI

Diagnostic Considerations with *P. Acnes*

P. acnes is a relatively slow-growing organism that can be difficult to isolate in routine cultures with standard incubation periods and can remain in the soft tissues even after adequate antisepsis. Lee et al. showed that after skin preparation, punch biopsies of seven of ten male volunteers were culture positive for *P. acnes* [50]. Matsen et al. showed that three of ten male patients had *P. acnes* growth from deep tissues during primary arthroplasty after skin preparation and intravenous antibiotics [51].

Many have recognized the need to incubate cultures for longer than standard incubation times of 5 days and to utilize both aerobic and anaerobic culture techniques, in order to improve the ability to detect *P. acnes*. Butler-Wu et al. recommended holding cultures for 13 days, as those that grew after this point were considered to be contaminants. They also noted that holding only the anaerobic cultures for prolonged incubation periods would have missed 29.4% of *P. acnes* isolates and suggest holding both aerobic and anaerobic cultures for this time frame [52]. More recently, Matsen et al. found that a culture protocol of obtaining four deep tissue specimens and culturing them for a minimum of 17 days in three different media (aerobic, anaerobic, and broth) had a 95% chance of detecting all *P. acnes* cultures in a cohort of patients undergoing revision shoulder arthroplasty [44]. Other factors have also been shown to impact *P. acnes* recovery, including preoperative antibiotic hold at the time of revision shoulder arthroplasty (increases *P. acnes* recovery) and specimen type (intraoperative tissue specimens have higher *P. acnes* recovery than fluid) [17, 35, 44, 53]. Ahsan et al. also demonstrated the uneven distribution of *P. acnes* within culture-positive revision shoulder arthroplasty cases, emphasizing the importance of taking an adequate number of culture samples at the time of revision surgery to avoid missing detection of *P. acnes* that may be present [53].

P. acnes-positive cultures have been reported in patients undergoing first time open shoulder surgery in multiple recent studies. Levy et al. cultured aspirates and tissue specimens in 55 consecutive patients undergoing primary shoulder arthroplasty and noted that 41.8% of patients were culture-positive for *P. acnes*. No patient developed a postoperative infection, though the authors treated culture-positive patients with 4 weeks of oral antibiotics and also suggested that *P. acnes* may be implicated as a possible cause for glenohumeral osteoarthritis based on the high positive culture rate [54]. Other recent studies, however, using strict specimen collection protocols and/or control specimens suggest that *P. acnes*-positive cultures during first time shoulder surgery may be less common and at least a portion of them likely represent contaminants. Maccioni et al. utilized a strict specimen collection protocol in 32 patients undergoing primary shoulder arthroplasty in which 5 capsule/synovium specimens were sent for culture and a sixth was sent for histopathology and noted that only 3 patients (9.4%) grew *P. acnes*, with only 1 showing growth on more than 1 specimen. Histopathology was negative for infection in all positive culture cases [55]. Mook and Garrigues also recently reported a 17.1% (14/82) rate of positive *P. acnes* cultures in patients undergoing first time open shoulder surgery, with most cases representing an isolated result (three capsule specimens taken per case) that grew late. In addition, a sterile gauze sponge was sent as a control culture specimen in all of the prospectively enrolled patients in the study and had a 13.0% (7/54) rate of positive culture (5/7 positive cultures grew *P. acnes*). Taken together, these studies suggest a contamination rate with *P. acnes*-positive cultures, likely due to the increased incubation times for these specimens and the increased handling of samples as a result of the longer culture times [56].

In the setting of revision shoulder arthroplasty, interpretation of a positive *P. acnes* culture result should be made in the context of the overall clinical picture. This should take into account other positive preoperative and intraoperative markers for infection, including traditional serum markers (ESR and CRP) and intraoperative frozen section findings, as well as newer synovial fluid biomarkers, if available, and the characteristics of the

positive culture result(s) themselves, such as the timing of the first positive culture and the number of positive culture results relative to the overall number of cultures taken. Such data taken together can help determine whether a positive culture is likely to represent a false-positive result consistent with contamination or a true positive finding that is concerning for infection. A recent study by Frangiamore et al. highlights this approach. In 46 patients who underwent revision shoulder arthroplasty and had at least one positive *P. acnes* culture, cases were classified into one of two groups based on culture results and other perioperative findings of infection: a probable true positive culture group and a probable contaminant group. Time to *P. acnes* growth in culture was found to be significantly shorter in the probable true positive culture group compared with the probable contaminant group (median of 5 days compared with 9 days). There were also significantly fewer days to *P. acnes* culture growth among cases with a higher number of positive cultures and a higher proportion of positive cultures, regardless of group classification [57].

Treatment

Treatment Options

There is no well-defined algorithm to guide treatment for PJI of the shoulder. Treatment should proceed with the goals of eradicating infection, improving shoulder function, and decreasing pain. A variety of patient-specific factors can help to guide the treating surgeon toward the appropriate treatment. These factors include the results of preoperative testing, chronicity of the infection, organism isolated, implant fixation, medical status of the patient, status of the soft tissues (rotator cuff, axillary nerve, and deltoid), and remaining bone stock. Treatment options for shoulder PJI include long-term antibiotic suppression, irrigation and debridement with implant retention, one-stage exchange arthroplasty with antibiotic-impregnated cement, two-stage exchange with antibiotic-impregnated cement spacer, resection arthroplasty with or without placement of a permanent antibiotic spacer, arthrodesis, and amputation [8, 15, 16, 19, 27, 28, 32, 35, 43, 45, 58–67].

In the hip and knee literature, a comprehensive periprosthetic infection (PJI) classification has been utilized to guide treatment. This classification is based on the time of onset of the infection following surgery and involves four types: Type 1 is the presence of positive cultures at the time of revision arthroplasty, type 2 is an acute infection detected within 30 days of arthroplasty, type 3 is an acute hematogenous infection that may occur at any time, and type 4 is a chronic infection [68]. Given the subtler appearance of shoulder PJI, it is sometimes difficult to apply this classification to shoulder PJI. For the ease of organization and to give a general framework, these criteria can be applied loosely to the shoulder.

Nonsurgical treatment of shoulder PJI is most often reserved for patients who are not candidates for surgery due to multiple medical comorbidities. There is also a group of patients who feel that their symptoms do not justify another surgery. For this subgroup of patients, long-term antibiotic suppression is an option. Long-term antibiotic suppression can be a reasonable option given the indolent nature of the infections and the lack of host immune response. There is no high-quality data regarding the outcomes of long-term suppressive antibiotics in the shoulder. Many antibiotics have been shown to be active against *P. acnes* isolated from orthopedic implants [69], and antibiotic selection and treatment should be co-managed along with an infectious disease specialist.

Surgery is the mainstay of treatment for those patients who are willing and able to undergo one or more additional operations. If an infection is diagnosed in the early postoperative period or develops as an acute hematogenous infection, treatment with irrigation and debridement along with component retention can be an appropriate treatment strategy. When chosen, it is important to perform a thorough and aggressive debridement of all tissues that appear to be involved in the disease process. If the humeral component is modular, separation of the head from the stem

will yield improved exposure of the glenoid and the ability to culture at the modular interface. In cases where RSA is in place, exchange of the polyethylene liner and glenosphere will accomplish the same goals. Following surgery, the patient should be placed on culture-specific IV antibiotics through a peripherally inserted central catheter (PICC) for a period of 6 weeks [70]. This is often followed by oral antibiotic therapy with the guidance of infectious disease. In the case of culture-negative infection, an antibiotic covering *P. acnes* should be used. Dennison et al. retrospectively reviewed ten shoulders in nine patients who underwent irrigation and debridement with component retention for acute postoperative or acute delayed onset hematogenous shoulder PJI. The assumption was made that because the diagnosis occurred within 6 weeks of the development of infection, no biofilm would be present and irrigation and debridement would be sufficient. Seven of the ten shoulders in this study retained components after irrigation and debridement at a mean of 4.1 years' follow-up. Five of the seven shoulders with retained components were placed on long-term suppressive antibiotics. Function was maintained in the shoulders that retained their prosthesis with forward elevation greater than 110° and external rotation greater than 40° in all shoulders. Deep infection recurred in the other three shoulders, and resection arthroplasty was subsequently performed [71].

Unfortunately, the majority of infections after shoulder arthroplasty are subclinical or subtle for long periods of time before a diagnosis is made because of the indolent nature of the common infecting organisms. Patients with chronic, indolent infection may also present after failure of a more conservative treatment option. In these situations, removal of the prosthesis is required to eradicate the infection. One- or two-stage reimplantation of components is the goal when the clinical scenario allows; however, in special situations resection arthroplasty alone can be used as the definitive procedure. The goal of the initial implant removal should be removal of the implant, aggressive debridement of bone and soft tissue, and removal of all cement or other foreign material [32, 35, 45, 58, 64, 66, 67]. A variety of instrumentation should be available for cement removal as well as for removal of the implant. Specialized sonic devices and fine-tipped, high-speed burrs can be used along with instruments such as reamers, rongeurs, curettes, saws, and osteotomes to aid in removal. Identification of the prosthesis prior to surgery with the help of previous documentation or radiographs is helpful, as many companies have removal tools developed for their particular implant. Fluoroscopic guidance is helpful during cement and component removal to visualize surrounding bone to avoid cortical perforations or fractures. In some cases, a longitudinal unicortical osteotomy (episiotomy) or a cortical window is needed to aid in implant removal. The episiotomy cut should be made the length of the stem and lateral to the bicipital groove to minimize the risk of unintended humeral fracture during implant removal. The split can be gently hinged open to loosen the stem and remove cement, or if needed, the split can be converted to a cortical window and secured back at the end of the case with a monofilament cerclage [72]. Depending on the clinical picture, removal of the implant with irrigation and debridement could be the definitive procedure. The other options are placement of an antibiotic spacer or reimplantation at the time of removal or in staged fashion.

Resection arthroplasty is reserved for patients with recalcitrant infections after failed shoulder arthroplasties, patients who do not have enough bone stock remaining to support a prosthesis or with a severe neurologic deficit that precludes a functional prosthesis, or those with medical comorbidities that prevent further operations. This technique should be used as a salvage option only as functional results are very poor, although significant pain relief can be obtained [32, 59–61, 73, 74]. Muh and colleagues reviewed 26 patients who underwent resection arthroplasty for failed primary total shoulder arthroplasty and found significantly improved pain scores and no change in function. They noted that forward flexion tended to be better in patients who had an anatomic implant removed when compared with those who had a RSA removed [74]. Rispoli followed 18 patients with resection arthroplasty

(13 for infected arthroplasty) and reported significant pain relief in all, though 5 still had moderate to severe pain. Patients had significant functional limitations, with mean elevation of 70° and mean external rotation of 31°, Simple Shoulder Test (SST) score of 3.1, and American Shoulder and Elbow Surgeons (ASES) score of 36 [60]. Despite low functional scores, Stevens et al. found that patients tend to be satisfied after resection in salvage situations, with 86% saying that would undergo the procedure again [73].

Permanent placement of an antibiotic cement spacer can be performed for the same indications as resection arthroplasty. An additional subset of patients may be satisfied with the pain relief and function of a spacer initially placed as part of a two-stage protocol and may not wish to undergo the second-stage reimplantation. A study of nine patients with antibiotic spacers who elected not to undergo reimplantation because of satisfaction with the spacer reported satisfaction in all nine patients, no or mild pain, and adequate performance of ADLs. Mean abduction was 75°, mean external rotation was 25°, and QDASH scores were 37.5 [16].

While removal of the implant can provide pain relief, the most predictable means of achieving satisfactory functional outcomes is by reimplantation either in one or two stages. One-stage exchange involves placement of a new prosthesis at the time of irrigation and debridement. Patients who undergo one-stage exchange arthroplasty are also treated with approximately 6 weeks of culture-specific intravenous antibiotics through a PICC line. This treatment option is best for patients who are infected with less virulent organisms, such as *P. acnes* [35, 75], and also commonly occurs in the setting of unexpected positive culture results following one-stage revision shoulder arthroplasty [17, 27, 28, 76, 77]. In this clinical scenario, a one-stage revision shoulder arthroplasty is performed due to an aseptic indication, with a lack of overt clinical findings of infection and negative perioperative diagnostic tests, but postoperative growth of intraoperative cultures occurs. Growth of *P. acnes* or other indolent bacteria is common in the setting of unexpected positive culture results.

Two-stage exchange arthroplasty consists of implant removal with irrigation and debridement with antibiotic cement spacer placement followed by a course of intravenous antibiotics and delayed reimplantation (Fig. 12.1). Based upon the hip and knee literature, two-stage revision is the most commonly accepted treatment of PJI of the shoulder, particularly in a more virulent organism. Placement of the intra-articular cement spacer serves to maintain length to prevent soft tissue contracture, as well as provide high concentrations of antibiotics to the area of resection. If the spacer provides adequate stability to the joint, the patient may perform gentle range of motion exercises to further prevent contracture. The antibiotic-impregnated cement spacer can be molded by the surgeon at the time of surgery with or without custom molds, or newer prefabricated designs can be used (Fig. 12.1). Antibiotic concentrations have varied across studies, but recommended amounts have ranged from 1.2 to 4.8 grams of tobramycin, 40 milligrams to 4.8 grams of gentamicin, 1–6 grams of vancomycin, and 4.5–6 grams of cefazolin per 40 grams of polymethylmethacrylate powder [16, 59, 65, 78].

For a two-stage exchange, the treating surgeon must ensure that the infection has been eradicated. After completion of antibiotic therapy, the patient is usually given a 4–6-week period off of antibiotics prior to placement of a new prosthesis. Serum lab evaluation (ESR, CRP) is again undertaken, and joint aspiration is performed after this antibiotic-free period to confirm the laboratory studies have normalized and the joint aspirate is negative [66]. As in the initial resection surgery, intraoperative tissue samples should be obtained for culture and pathology, including frozen section, prior to reimplantation [66]. If there are concerning signs that an infection is still present, such as positive preoperative bloodwork or aspirate or positive intraoperative frozen section, a repeat debridement procedure with placement of a new antibiotic spacer should be performed.

If the infection has been cleared, the choice of prosthesis is made based on the status of the bone, rotator cuff, and deltoid. An anatomic TSA or hemiarthroplasty may be possible if glenoid bone

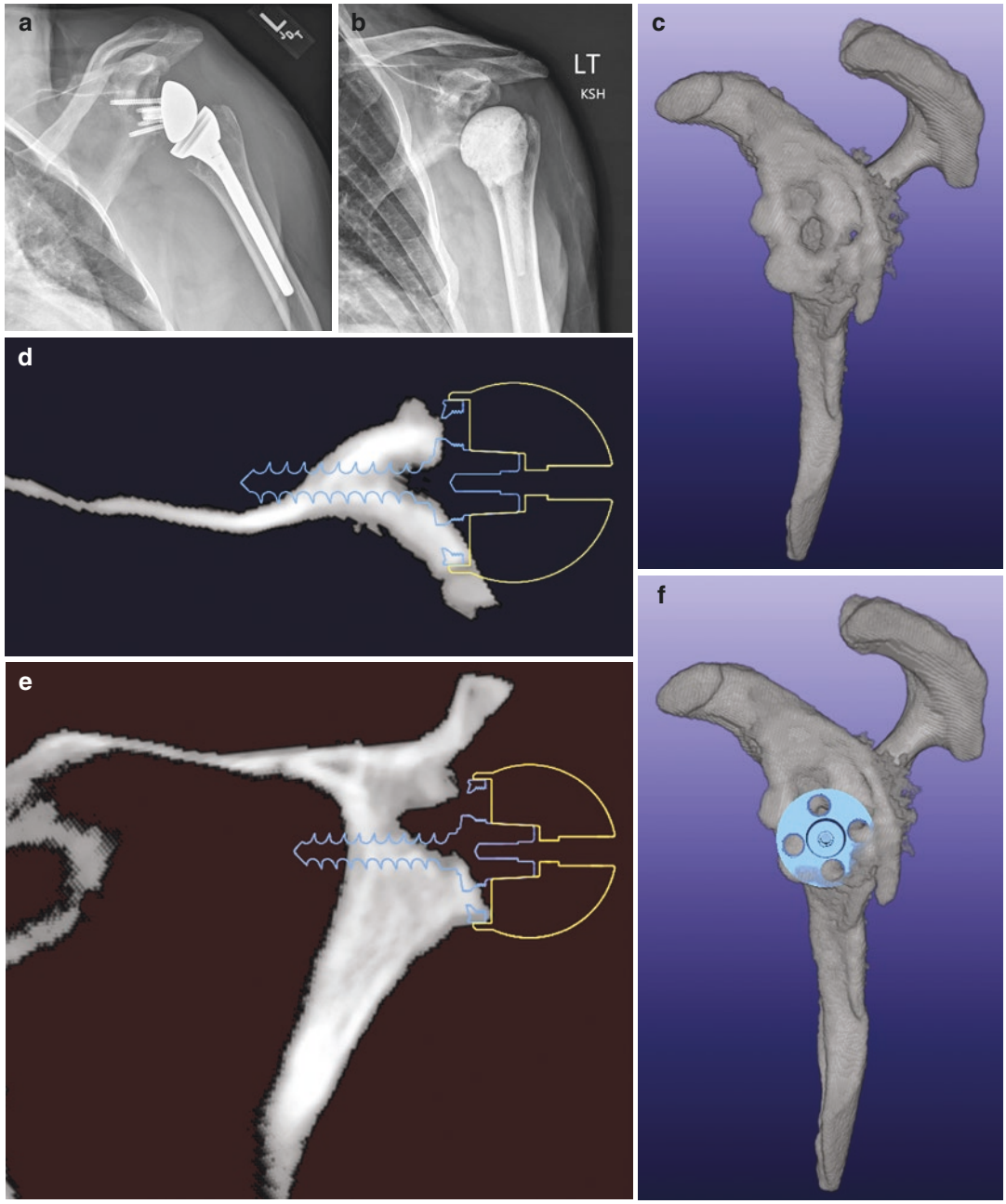

Fig. 12.1 (**a**) Anteroposterior (AP) radiograph of a left reverse total shoulder arthroplasty 1 year after surgery with signs of radiolucencies around both the glenoid and humeral component, worrisome for loosening. Preoperative work-up for infection showed elevated ESR and CRP, and the patient was taken for revision surgery with high suspicion for infection. Intraoperative frozen section tissue specimens demonstrated acute inflammation concerning for infection, and intraoperative cultures subsequently grew out *P. acnes* (7/9 cultures positive). The patient underwent two-stage exchange, with (**b**) placement of a temporary antibiotic-impregnated cement spacer and a 6-week course of IV antibiotics. (**c**) Preoperative three-dimensional CT scan was obtained prior to reimplantation surgery and demonstrated a central contained glenoid defect at the prior center peg site. (**d**–**f**) Preoperative planning software was utilized to plan the implant position prior to reimplantation surgery. (**g**) AP radiograph following reimplantation with a reverse total shoulder arthroplasty. Cancellous allograft bone chips were used to fill the central contained glenoid defect, and the humeral component was secured with antibiotic-containing cement

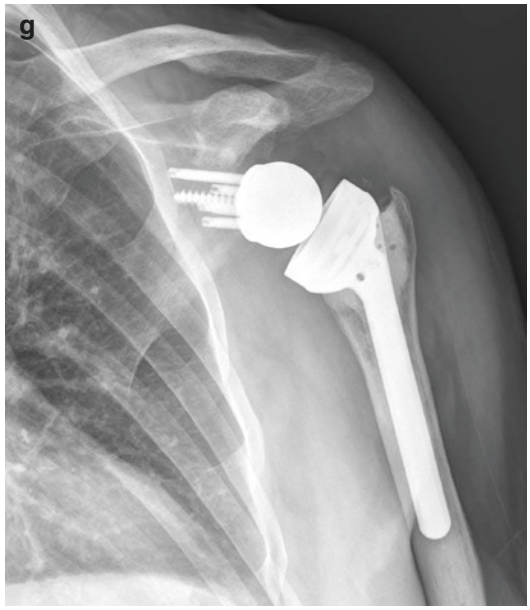

Fig. 12.1 (continued)

stock is sufficient and the rotator cuff and deltoid are functional and intact. Hemiarthroplasty or RSA should be utilized in cases where glenoid deficiency precludes placement of an anatomic glenoid component and/or soft tissue defects, particularly rotator cuff deficiency, are present. RSA may provide the most reliable functional outcome, particularly in the setting of rotator cuff deficiency and advanced glenoid bone loss. Preoperative computed tomography (CT) may be useful for surgical planning in order to better evaluate the degree of glenoid bone loss that is present (Fig. 12.1).

Arthrodesis, although rarely performed, is an option in those with axillary nerve or brachial plexus injuries or combined loss of the rotator cuff and deltoid. Functional outcome is typically better than resection arthroplasty as it provides a stable platform for distal function; however, it is a technically demanding procedure given the bone loss typically present after implant removal. Scalise and Iannotti reported on a series of seven patients who underwent arthrodeses after failed arthroplasty and noted the need for a vascularized fibula in three patients and subsequent operations to obtain union in four [79].

Treatment Outcomes of One- and Two-Stage Exchange

Evaluating treatment outcomes for shoulder PJI is somewhat difficult given the small amount of literature available and its heterogeneity. Most studies report on revision arthroplasty utilizing non-standardized treatment protocols with variable follow-up lengths. The evidence that is available is primarily retrospective case series, typically involving a small number of patients. A few comparative studies are available at this point, but there is yet to be any prospective data published. Comparing results of one- and two-stage revision approaches is difficult due to the lack of uniform criteria across studies in choosing each approach and in the definitions of PJI. Functional outcomes are also difficult to compare since the majority of the data available is based upon revision to hemiarthroplasty, with only more recent data including revision to RSA. Given the limited data, it is difficult to draw conclusions on specific treatment methods. Below we summarize outcomes for one- and two-stage exchange.

One-Stage Exchange

Hsu and colleagues recently compared outcomes of one-stage exchange in *P. acnes* culture-positive (>1 culture positive) revisions (27 cases) to a control group of one-stage revisions with no culture growth or an isolated positive *P. acnes* culture (28 cases). At the time of revision surgery, five sets of cultures were obtained prior to administration of antibiotics, irrigation and debridement, and exchange arthroplasty in all patients. In their treatment protocol, all patients with multiple positive *P. acnes* cultures were given a 6-week course of IV antibiotics followed by 6 months of oral antibiotics. The control group of patients discontinued antibiotics at 3 weeks after cultures were final. At a mean follow-up of 47.8 months, the Simple Shoulder Test (SST) scores improved in both groups with no significant difference in pain, stiffness, or component loosening between the two groups. There were no recurrent infections in the 27 culture-positive shoulders [35].

Ince et al. reported on their experience with one-stage exchange for the treatment of infected shoulder arthroplasty [63]. Sixteen cases were performed, and 15 were converted to a hemiarthroplasty and 1 to a RSA. All revision implants were cemented with antibiotic-impregnated cement. The two most common isolated organisms were a *Staphylococcus* species (8 shoulders) or a *Propionibacterium* species (4). Mean course of antibiotic therapy was only 8.6 days (range, 5–14) and was stopped once the CRP began to decline. Nine patients were available for follow-up at a mean of 5.8 years (range, 1.1–13.25). Six patients were satisfied with their outcome. Mean shoulder abduction was only 51.6°. The mean Constant score was 33.6 and the mean UCLA score was 18.3 (maximum score, 35). There were three cases not in the final follow-up that required revision surgery: one for a periprosthetic fracture, one for an acromial pseudarthrosis, and one for recurrent instability. There were no recurrent infections, and the authors concluded that eradication of infection is possible with a one-stage exchange [63].

More recently, Beekman et al. reported on a series of 11 cases of one-stage revisions performed for infected reverse TSA [62]. All patients were revised to a cemented RSA with antibiotic-impregnated cement. No primary reverse TSA was loose at the time of revision surgery. The isolated organisms were *P. acnes* (7 shoulders), coagulase-negative *Staphylococcus* (5), methicillin-resistant *Staphylococcus aureus* (1), and *Escherichia coli* (1), including two multibacterial infections. A minimum of 3 days of IV antibiotic therapy was given to all patients, and the minimum overall course of antibiotic treatment (combined IV and oral) was 3 months. Antibiotics were stopped when the ESR and CRP normalized for 6 weeks. Mean follow-up was 24 months (range, 12–36). There was one recurrent infection that persisted despite a subsequent two-stage exchange. The organism was *Propionibacterium* species, and the patient was ultimately cleared of the infection after placement of a long-term spacer. Overall, the mean Constant score was 55 at final follow-up [62]. Klatte et al. evaluated 35 patients treated with single-stage revision to various implants and a mean of 10.6 days of antibiotics. Two patients (5.7%) developed recurrent infection and were treated with resection arthroplasty. Mean Constant scores were 43.3 for hemiarthroplasties, 56.0 for bipolar hemiarthroplasties, and 61 for RSAs [75]

Two-Stage Exchange

Two-stage exchange is still the most commonly recommended treatment option available in shoulder PJI, though this is mostly extrapolated from the success of this treatment option in the hip and knee literature. With many cases of shoulder PJI due to chronic, indolent infections, a two-stage exchange may not be necessary in all instances, but further data is needed to determine the criteria for performing a one- versus a two-stage exchange.

Strickland et al. evaluated 19 shoulders that were treated with two-stage exchange for a deep shoulder prosthetic infection [8]. Four cases had previously been treated with either long-term

antibiotic suppression (2) or irrigation and debridement with implant retention (2) and had failed to eradicate the infection. All patients underwent placement of an antibiotic-impregnated spacer after implant removal and received 4–6 weeks of organism-specific IV antibiotic therapy. The most common isolated organisms were either *P. acnes* or *coagulase-negative Staphylococcus* (10 shoulders) and *Staphylococcus aureus* (3). Mean time to reimplantation was 11 weeks (range, 6–31) after resection and was either with hemiarthroplasty (13) or TSA (5). Mean follow-up was 35 months (range, 24–80), with mean shoulder elevation to 89°, mean external rotation to 43°, and mean internal rotation to L5. Pain was significantly improved ($p = 0.0001$) postoperatively, but results were rated as unsatisfactory in 13/19 (68%) shoulders. There were 14 complications and 5 further operations following reimplantation, including 2 irrigation and debridements and a resection arthroplasty in a patient with continued infection. The infection was considered cleared in 12/19 (63%) shoulders. Seven recurrent infections were defined based on six patients requiring long-term antibiotics due to continued concern for infection and the one patient who required a resection arthroplasty [8].

Coffey et al. reported on their experience with two-stage exchange for infected shoulder arthroplasty and native septic arthritis using a commercially produced antibiotic-impregnated spacer [65]. The series consisted of 16 shoulders, 11 of which were infected shoulder prostheses. This included six hemiarthroplasties, three RSA, and two standard TSA. An organism was isolated in 12 of 16 cases, including 3 with methicillin-resistant *Staphylococcus aureus*, 3 with *Staphylococcus epidermidis*, and 1 with *P. acnes*. All patients underwent placement of a commercially manufactured gentamycin-impregnated spacer after implant removal and received culture-specific IV antibiotic therapy postoperatively. Mean IV antibiotic treatment was 5.6 weeks (range, 2–6). Reimplantation occurred when the patient's serum IL-6 level was decreasing or had normalized at a mean of 11.2 weeks (range, 6–30) after implant removal and spacer placement. Nine shoulders were reimplanted with a RSA and two with a standard TSA, and one shoulder underwent arthrodesis because of deltoid deficiency. Four patients refused revision and retained their antibiotic spacer. Mean follow-up was 20.5 months (range, 12–30) after spacer placement. Pain was improved, with mean active forward flexion increased from 65° before spacer placement to 110° at final follow-up and mean active external rotation increased from −5° to 20°. The mean UCLA score was 26, the mean Simple Shoulder Test (SST) score was 6.6, the mean ASES score was 74, and the mean Constant score was 57 at final follow-up. None of the postoperative outcome measures were separated out by preoperative etiology (infected shoulder arthroplasty versus native septic arthritis) or final revision implant. There were no recurrent infections [65].

Sabesan et al. evaluated the outcomes of two-stage exchange in the treatment of infected shoulder arthroplasty, in which reimplantation was with a reverse TSA [64]. Twenty-seven shoulders were identified that had undergone two-stage reimplantation for a shoulder PJI, with 17 revised to a RSA. The most common isolated bacteria were a *Staphylococcus* species (7 shoulders) and *P. acnes* (5). Patients received organism-specific IV antibiotic therapy for a mean of 6.3 weeks (range, 4–54) postoperatively and had a median of 4.0 months (range, 1.8–61) between explant and reimplantation. Mean follow-up was 46.2 months (range, 22–80). There was one recurrent infection from *P. acnes* that was ultimately cleared with a second two-stage exchange. Mean Penn shoulder score was significantly improved from preoperative levels at final follow-up (24.9–66.4), with mean forward flexion of 123° and mean external rotation of 26°. Seven complications developed postoperatively, requiring seven additional surgeries. One postoperative hematoma developed that required irrigation and debridement. Five surgeries were performed for instability with polyethylene exchange or revision of the glenosphere. The other additional surgery was the repeat two-stage exchange for recurrent infection [64].

Recently, two more retrospective studies have evaluated two-stage exchange for shoulder PJI. Buchalter and colleagues reviewed 19 patients with a mean time from index procedure to revision

of 40 months. Diagnosis was made based upon serum lab studies, clinical presentation, and aspiration. A standard two-stage protocol was undertaken with resection and antibiotic spacer placement. All patients were given 6 weeks of intravenous antibiotics, and infectious disease was consulted. Reimplantation was undertaken when the patient had been found to have cleared the infection based upon lab studies and aspiration. A deep infection recurred in 26% of the 19 patients. Overall complication rate was 42% with two patients having aseptic loosening, one with fracture, and five developing recurrent infections. Forward elevation significantly improved after two-stage revision, but external rotation did not improve. The authors found that patients infected with *P. acnes* had poorer outcomes than those who did not isolate *P. acnes* [67]. In another retrospective review, Assenmacher et al. reviewed 35 shoulders with PJI treated with two-stage exchange. The organisms isolated from the shoulder were *P. acnes* in 13 cases, *Staphylococcus epidermidis* in 12, and methicillin-resistant *Staphylococcus aureus* in 2. No growth was obtained in four of the cases. VAS pain scores were significantly improved from a mean of 4.4 to 2 out of 5. Mean forward elevation improved from 64° to 118°. Mean ER improved from 14° to 41°. Outcome was excellent in 10, satisfactory in 12, and unsatisfactory in 13 on the Neer modified rating scale. Function and pain did not change depending on prosthesis implanted. There were six reinfections, three due to *P. acnes*, two from *Staphylococcus epidermidis*, and one from polymicrobial with methicillin-resistant *Staphylococcus aureus* and *Enterococcus*. While infection was eradicated in 85% of patients using two-stage revision, the rate of unsatisfactory results was nearly 40% [58].

Comparative Studies

Several studies have directly compared treatment methods. Verhelst et al. evaluated 11 patients treated with resection arthroplasty and 10 patients with permanent spacers and noted no difference in recurrence rate or functional outcomes [59]. Codd et al. compared resection arthroplasty in 5 patients to reimplantation in 13 patients. Pain relief was similar in the two groups, though elevation was 66° compared to 117°, external rotation was 27° compared to 38°, and internal rotation was to the sacrum compared to L2 [32]. Stine compared permanent spacers to two-stage exchange in 30 patients. There were no recurrent infections and no differences in functional outcomes [66]. Cuff et al. compared one-stage exchange in 10 patients to two-stage exchange in 12 patients. There were no recurrent infections and no differences in functional outcomes between groups; however, there were 11 complications in 7 shoulders [45]. More recently, Stone et al. retrospectively compared one- and two-stage exchange in 79 patients with shoulder PJI but evaluated patients in 3 groups, those that underwent an incomplete one-stage exchange with some component retention (15 patients), those that underwent a complete one-stage exchange (45 patients), and those that underwent a two-stage exchange (19 patients). There was no difference in noninfectious complications, pain, and functional improvement between groups; but one-stage incomplete exchange and growth of either *S. aureus* or coagulase-negative staph species were found to be significantly associated with reoperation for infection [80]. Nelson et al. also recently performed a systematic review of outcomes in the treatment of shoulder PJI, evaluating a total of 669 patients across 30 studies. *P. acnes* was the most commonly reported bacteria in the included studies. They found no significant differences in eradication rates of PJI in one- and two-stage exchange surgeries and resection arthroplasties (all >90%), while antibiotic suppression (50%) and irrigation and debridement with implant retention (68.6%) had significantly worse PJI eradication rates (Table 12.3) [81].

Studies with Unexpected Positive Culture Results

Several studies have evaluated outcomes in case with unexpected positive culture results. Topolski et al. reported on 75 cases of revision arthroplasty with unexpected positive cultures. Fifty-four of 75 were treated with standard postoperative antibiotics. Ten patients underwent a second revision surgery, only one of which was for a documented recurrent infection, though seven of

Table 12.3 Infection outcomes by treatment regimen

	Antibiotics only	Resection or arthrodesis	I&D, implant retention	Antibiotic spacer	One-stage revision (+UPC)	One-stage revision (−UPC)	Two-stage revision
Total	8	90	35	31	282	72	97
Successful treatment	4	84	24	28	254	66	91
% Cured	50%	93.3%	68.6%	90.3%	90.1%	91.7%	93.8%
Failed treatment	4	6	11	3	28	6	6
% Failed	50%	6.7%	31.4%	9.7%	9.9%	8.3%	6.2%

Used with permission from Nelson et. al. [81]
Data pooled from the following references: [1, 3, 5–7, 9, 10, 17, 22–24, 28, 29, 34, 41, 43–45, 50–57]
I&D irrigation and débridement, *+UPC* included unexpected positive cultures as one-stage revisions, *−UPC* excluding unexpected positive cultures

the ten had positive cultures at the time of the second revision [27]. Kelly and Hobgood evaluated eight patients with unexpected positive cultures and noted that two of eight developed a late infection. They recommended placing all revisions on oral antibiotics until cultures are negative and that culture-positive patients should be treated with 6 weeks of IV antibiotics [28]. Grosso et al. similarly reviewed 17 patients with unexpected positive cultures who were not treated with prolonged antibiotic therapy and noted recurrent infection in 1 of 17. There was no difference in recurrence rate or functional outcomes in these patients compared to one- and two-stage revisions for infection [82]. In the largest series to date, Foruria et al. evaluated the results of 107 consecutive cases of revision shoulder arthroplasty without preoperative or intraoperative signs of infection that were found to have at least one positive intraoperative culture. Sixty-eight (64%) of the cases grew *P. acnes*. Following one-stage revision, 53 cases were treated with an extended course of antibiotics, while 54 were not. At mean follow-up of 5.6 years, 11/107 (10%) cases had a subsequent positive culture result either by aspirate or during a second revision surgery that matched the culture result of the original revision surgery. Ten of the cases were *P. acnes* positive. Treatment with antibiotics did not appear to lower the risk of having a second positive culture result [77].

Authors Preferred Management

Currently, our preferred management approach for a chronic PJI of the shoulder is a two-stage reimplantation when one or more perioperative signs of infection are present, particularly positive serum ESR and CRP, positive preoperative synovial aspirate, positive intraoperative gross findings of infection, and positive intraoperative frozen sections. However, many patients with a chronic indolent infection may have none of these positive perioperative signs of infection and, therefore, undergo a one-stage revision shoulder arthroplasty for an aseptic indication. We, therefore, routinely maintain all presumed aseptic revision shoulder arthroplasty cases on oral antibiotics postoperatively until all cultures are negative, due to the possibility of postoperative growth of intraoperative cultures. In this scenario, cases found to have multiple positive intraoperative cultures are treated with 6 weeks of IV antibiotic therapy, with transition to a more extended course of oral antibiotics based on the clinical presentation. If only one intraoperative culture turns positive, no further antibiotic therapy may be needed if the clinical picture is suggestive of a probable contaminant result. This is particularly true if the culture growth is late and all prior components were removed at revision surgery; however, retention of some of the prior components may still be an indication for postoperative antibiotic treatment.

Conclusions

Diagnosis and treatment of infection after shoulder arthroplasty is a complex and challenging problem. Evaluation of a persistently painful shoulder arthroplasty should start with a thorough history and physical examination and a high index of suspicion for infection by the treating surgeon. Serum laboratory studies and other standard diagnostic tests have been shown to be less sensitive in the shoulder than in the hip and knee but can still play a role in diagnosis if a positive result is obtained. Newer synovial biomarker tests have shown promise for diagnosing shoulder PJI. Most studies on outcomes of treatment for infected shoulder arthroplasty report results on only a small number of patients, often with varying treatment protocols. This lack of uniformity in treatment approach, as well as in reported outcome measures, makes it difficult to draw definitive conclusions on specific treatment methods. As the most common clinical scenario in shoulder PJI is a chronic infection involving an indolent organism, further data is particularly needed to better define the indications and outcomes in cases of one- and two-stage exchange. Improved diagnostic testing to better identify *P. acnes* and other less virulent organisms preoperatively or intraoperatively may help to more clearly define indications for one- versus two-stage exchange, as well as the need for postoperative antibiotic therapy in the setting of a presumed aseptic one-stage revision with unexpected positive culture results.

This chapter highlights the lack of precise algorithms for both diagnosis and treatment of shoulder PJI. Essential to development of such algorithms is arriving at a consensus definition for shoulder PJI, based on a combination of preoperative and intraoperative findings and intraoperative culture results. The evaluation and management of the painful shoulder arthroplasty remains highly variable and needs to be standardized in such areas as preoperative surgical site preparation, choice and timing of intraoperative antibiotics during revision surgery, number and type of intraoperative cultures obtained during revision surgery, culture methods and length of time for culture incubation, and choice and length of postoperative antibiotic therapy. A consensus definition of PJI and a standardized approach to evaluation and management will aid in developing and interpreting future research studies and will ultimately lead to more refined diagnostic algorithms and clinical treatment pathways. Currently, decision-making for each patient should be based on the results of preoperative testing, time since the index arthroplasty, the infecting organism, patient comorbidities, the status of implant fixation, glenoid and humeral bone stock, and the status of the deltoid and rotator cuff.

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