shoulder PJI using either single or two-stage exchange with regard to complications or functional outcomes.

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QUESTION 3: What are the indications for one- versus two-stage revision in subacute or chronic shoulder periprosthetic joint infection (PJI)?

RECOMMENDATION: The indications for one-stage versus two-stage exchange are unclear at this time. The pooled data demonstrate one-stage exchange to be superior to two-stage exchange, but this may be a result of selection bias and other factors.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 96%, Disagree: 0%, Abstain: 4% (Unanimous, Strongest Consensus)

RATIONALE

A comprehensive literature review was performed to identify all studies on revision shoulder arthroplasty for periprosthetic joint infection (PJI). Terms used for the search included "infection," "shoulder replacement," "arthroplasty," "1-stage," "2-stage," "reimplantation," "prosthetic-related infection" and included "resection," "spacer" or "exchange" among others using PubMed, Scopus and Embase through February 2018. Inclusion criteria for our systematic review were all English language studies (Level I-IV evidence) that reported on single or two-stage revision, infection eradication for revision shoulder arthroplasty with a minimum follow up of twelve-months and minimum of five patients for analysis. Exclusion criteria for our review were all non-English language studies, papers that exclude single or two-stage exchange, review papers, case reports or technique articles without outcome data. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria were applied. Title and abstract screen was conducted of 248 results and a full text review of 66, identified 31 articles that met inclusion and exclusion criteria for final review.

The purpose for this review was to understand and compare the role of single-stage and two-stage exchange for the treatment of shoulder PJI. Two-stage exchange arthroplasty with implant removal, irrigation and debridement (I&D), insertion of antibiotic spacer, antibiotic treatment, followed by re-implantation has been suggested as gold standard for treatment of shoulder PJI [1]. Varying studies collected demographics, timing of infection, associated pathogens, surgical treatment, antibiotics, eradication rate for infection, surgical complications and functional outcomes with two-year follow-up minimum. We identified 12 articles that evaluated one-stage exchange and 27 articles that evaluated two-stage exchange. The majority of papers reported preoperative laboratory values to diagnose PJI based on elevated white blood cell count, C-reactive protein and/or erythrocyte sedimentation rate. Clinical findings such as draining sinus, erythema or swelling were inconsistently reported. Most studies reported the number of joint aspirations performed and resulted positive with microbial growth. Although there was inconsistent reporting of timing of infection, the majority of studies that reported timing of infection used terms from Sperling et al. and Strickland et al. with acute meaning < 3 months, sub-acute meaning 3-12 months and chronic > 12 months [2,3]. There was consistent reporting of the pathogens found either pre- or intraoperatively. *Cutibacterium acnes* (*C. acnes*) was the most common organism identified with 160 cases followed by *Coagulase-negative Staphylococcus* (CoNS) with 93 cases [2,4–14]. There were 57 reported cases of polymicrobial cases and 27 cultures that resulted in no growth [4–8].

To address the stated question, we reviewed studies in aggregate for sub-acute and chronic infection when treated with either single

TABLE 1. Reinfection and complications for single stage exchange

Cases	Reinfection Rate	Pathogens	Constant Score (mean)	Complication Rate
161 Total 13 Subacute 8 Chronic	5.6 % ($p < 0.001$)	72 *C. acnes* 29 CoNS 20 MSSA 3 MRSA	49.1 ($p < 0.11$)	12.7 % ($p < 0.001$)

CoNS, Coagulase-negative *Staphylococcus*; MSSA, methicillin-susceptible *Staphylococcus aureus*; MRSA, methicillin-resistant *Staphylococcus aureus*

TABLE 2. Reinfection and complications for two-stage exchange

Cases	Reinfection Rate	Pathogens	Constant Score (mean)	Complication Rate
325 Total 46 Subacute 74 Chronic	11.4 % ($p < 0.001$)	88 *C. acnes* 64 CoNS 33 MSSA 56 MRSA	51.1 ($p < 0.05$)	21.9 % ($p < 0.001$)

CoNS, Coagulase-negative *Staphylococcus*; MSSA, methicillin-susceptible *Staphylococcus aureus*; MRSA, methicillin-resistant *Staphylococcus aureus*

or two-stage revision summarized in Tables 1 and 2. Four studies directly compared revision success rate for shoulder PJI with single-stage exchange in sub-acute or chronic presentation. The reinfection rate was 12.5% for chronic cases and 5.3% for sub-acute cases [4,14,15]. Regarding two-stage exchange, three studies specifically reported success rates for either sub-acute or chronic shoulder PJI. Reinfection rate was 6.3% for chronic PJI and 29.4% for sub-acute PJI treated with two-stage exchange [2,4,15]. Several other studies reported the timing of infection but did not compare revision failure rates according to the subgroups of acute, sub-acute or chronic PJI groups. In aggregate, using a frequency-weighted mean, the reinfection rate was 5.6% for one-stage exchange compared to 11.4% for two-stage exchange, which was statistically significant ($p < 0.001$).

Analyses of complications related to single or two-stage exchange in acute, sub-acute or chronic infection were limited. In aggregate, all surgical complications reported include aseptic loosening, fracture, nerve palsy, dislocation and hematoma. Our systematic review found a 12.7% complication rate for single-stage exchange compared to a 21.9% complication rate for two-stage exchange, which was statistically significant. Although this finding suggests that patients undergoing two-stage exchange have 1.72 times the risk of intra- or postoperative complication, the analysis was not able to account for likely bias in the selection of treatment. The selection bias cannot be over-emphasized—it very well may be that cases with more severe infections were preferentially treated with two stage while less severe infections were treated with single-stage revision.

Frequency-weighted mean Constant Murley Score (CMS) was 49.1 for single-stage patients and 51.1 for two-stage exchange, which was similar to prior findings [7,15]. In the single-stage studies, a total of 57 patients had 78.2 degrees of FF; 42 patients had 52.4 degrees of abduction and 59 patients had 25.4 degrees of external rotation. Two-stage exchange papers reported 194 patients had 98.9 degrees of FF, 72 patients with 52.4 degrees of abduction and 144 patients with 29.2 degrees of external rotation. No studies compare the timing of infection and treatment with single or two-stage revision.

All papers identified are retrospective thus contain significant selection bias. While our findings in aggregate suggest single-stage exchange is a viable option for PJI, there are few studies that address reinfection associated with various risk factors such as pathogens, timing of infection or diagnostic features such as obvious clinical findings of infection. Thus, we cannot recommend using single-stage exchange in place of two-stage exchange for shoulder PJI without further investigation.

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QUESTION 4: Is there a role for preoperative joint aspiration prior to reimplantation during two-stage exchange for shoulder periprosthetic joint infection (PJI)?

RECOMMENDATION: There is a dearth of information on the role of preoperative joint aspiration prior to second stage revision after treatment of shoulder PJI. Furthermore, several studies have pointed to the high incidence of "dry taps" and false negative cultures from joint aspirates. Thus, there is little evidence in support of routine preoperative aspiration prior to second stage reimplantation.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 88%, Disagree: 4%, Abstain: 8% (Super Majority, Strong Consensus)

RATIONALE

A systematic review of the published literature was performed on PubMed using the search terms Shoulder (Title) AND [Periprosthetic OR reverse shoulder OR total shoulder OR arthroplasty OR replacement OR prosthesis (Title/ Abstract)] AND [Infection OR infected OR septic OR sepsis OR PJI OR propionibacterium OR acnes OR staphylococcal OR staphylococcus OR second stage OR OR staged OR revision OR spacer OR two-stage OR two stage OR reimplantation OR purulent OR purulence OR sinus tract (Title)]. This search yielded 255 articles. All titles were reviewed and articles with potential relevance had their abstracts reviewed. In total, with full texts reviewed, 31 articles where considered relevant to this topic in some fashion. Articles were deemed relevant if they included any aspirate information on patients with shoulder arthroplasties. These articles were used to make the recommendation. The reference lists of the included articles were further searched to identify other references that may have been omitted.

Controversy remains regarding the best surgical treatment of shoulder PJI. The literature documents interventions including open debridement with component retention or liner exchange, single stage re-implantation comprising removal of all components and immediate re-implantation after thorough debridement and lavage, resection arthroplasty after removal of all components and two-stage re-implantation. The latter involves a first stage that includes removal of all components followed by debridement, and in many cases insertion of an antibiotic impregnated polymethylmethacrylate cement spacer for local antibiotic delivery and to preserve soft tissue tension. The patient is then treated with intravenous (sometimes followed by oral) antibiotics and monitored, typically with serial serologic evaluation, prior to the second surgery (second stage revision) at which time the spacer is removed and new components are re-implanted.

In patients who undergo two-stage re-implantation for shoulder PJI, shoulder joint aspiration or arthrocentesis prior to second stage revision is one method to evaluate for persistent infection after the first stage explantation and subsequent antibiotic treatment. The aspirate can be sent for cultures, leukocyte cell count and differential, and also for analysis of biomarkers such as alpha-defensin. Shoulder aspiration is an established diagnostic tool and is commonly used (although not routinely) as part of the workup of PJI, including shoulder PJI.

However, there is little published information on the use of shoulder aspiration prior to second stage revision. In addition, there is no data documenting an advantage of shoulder aspiration over no aspiration or over any alternative diagnostic tool for shoulder PJI. Sabesan et al. reported that 12 of 17 patients had preoperative aspiration prior to the first stage. re-implantation [1]. Fluid was obtained for culture in 10 and 6 had positive cultures. Prior to the second stage the patients were ruled out for persistent infection with preoperative erythrocyte sedimentation rate, C-reactive protein (CRP), white blood cell (WBC) count and a negative preoperative aspirate. One of the 17 patients had intraoperative frozen section that was positive for acute inflammation and had repeat treatment for infection. Two small case series studies recommend preoperative aspiration prior to considering second stage revision, but only in cases with persistently elevated CRP and WBC [2,3]. Buchalter et al. have described their algorithm for two-stage re-implantation for shoulder PJI but do not mention shoulder aspiration as a factor in their timing of second-stage revision [4]. Patients were offered a second stage reimplantation if they had no clinical signs of infection and their inflammatory markers normalized.

If shoulder joint aspiration is considered in the evaluation for PJI, it is typically recommended to hold antibiotics for at least 14 days prior to aspiration [2,3,5]. It is also important to note that a negative culture of fluid aspirate or dry aspirate is not diagnostic of a resolved infection based on studies that include preoperative shoulder aspirations [5,6].