Review Article

Comparison of surgical treatment options in periprosthetic shoulder infections: a systematic review from 2016 to 2022

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Background: Periprosthetic shoulder infection (PSI) management proves to be challenging because of patient morbidity, poor outcomes and need for reoperations. Different surgical treatment methods have been defined; however, a prominent method could not be determined. This systematic review investigated the most recent articles about various treatment modalities used in the surgical treatment of PSI to find the most effective method in terms of infection clearance and function.

Methods: The keywords were searched using PubMed (MEDLINE), ScienceDirect (Elsevier), and Google Scholar databases on September 30, 2022. Studies which report on operative treatment and have longer than 2-year follow-up were included in this review. Of the 555 studies in total, 16 were reviewed. The absence of symptomatic persistent infection (PI) during follow-up was regarded as a satisfactory outcome. Functional outcomes were analyzed according to the reported mean pooled Constant and Murley Score (CMS) and shoulder forward elevation degree (FE) for each treatment group.

Results: A total of 339 patients (139 female, 197 male) with 342 shoulders from sixteen studies were included. The mean age of the patients was 67.5±3.8 years, mean follow-up duration was 53.3±19.5 months. In total, 217 shoulders were treated with two-stage revision, 59 were treated with one-stage revision, 37 were treated with definitive spacer, 23 were treated with debridement, antibiotics, and implant retention (DAIR), and 6 were treated with resection arthroplasty. The PI rate in whole treatment groups was 9.9%. The PI rate was significantly highest in the DAIR group (30.4%, P=0.001), while there was no significant difference between other treatment groups (P=0.23). CMS and FE were available for 156 and 190 shoulders, respectively. CMS was highest in the one-stage revision group (63.4±5.9, P=0.001), and FE was highest in the DAIR group (119.3°±28.5°, P=0.001).

Conclusions: The revision surgeries (one-stage and two-stage revision) were more effective than the non-revision surgeries in functional outcomes. In terms of infection clearance, revision procedures were more successful. Surgeons should prefer revision methods over non-revision procedures when feasible.

Keywords: Shoulder arthroplasty; periprosthetic infection; surgical treatment; systematic review

Received: 25 November 2022; Accepted: 17 April 2023; Published online: 30 April 2023.

doi: 10.21037/aoj-22-48

View this article at: https://dx.doi.org/10.21037/aoj-22-48

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Introduction

In recent years, there have been tremendous improvements in implant design and surgical technique in shoulder arthroplasty. Yet, these do not appear to provide a solution for the growing problem of infection. As the number of joint replacement surgeries is projected to rise (1), the number of periprosthetic joint infection (PJI) is considered to follow, as well (2). This is also valid for shoulder arthroplasty (3).

Periprosthetic shoulder infection (PSI) is one of the most challenging case scenarios as its diagnostic work-up may be inconclusive and usually requires revision shoulder arthroplasty when the diagnosis is established. Eradicating the causative microorganism is the primary goal with antibiotics and surgery, but infection prevalence may scale up to 16% despite appropriate treatment (4).

Among PSI, *Cutibacterium acnes* (*C. acnes*), coagulase-negative *Staphylococcus*, and *Staphylococcus aureus* (*S. aureus*) are the most common pathogens isolated in the peri-operative cultures (5). Infectious studies and microbiological tests usually require an antibiotic-free interval of 2 weeks and take at least 2 weeks more to culture. These can delay and complicate infection management even further.

Formerly, non-revision procedures, debridement, antibiotics, and implant retention (DAIR), resection arthroplasty, and definitive spacer methods were utilized in the treatment of infected shoulder arthroplasty, but they have proven to be inadequate in terms of both infection clearance and functional outcomes. Revision procedures, on the other hand, can achieve reliable outcomes (6-10).

The primary goal of this systematic review is to investigate the most current literature regarding surgical treatment methods to manage PSI effectively. We present the following article in accordance with the PRISMA reporting checklist (available at https://aoj.amegroups.com/article/view/10.21037/aoj-22-48/rc) (11).

Highlight box

Key findings

- The revision procedures were more successful in terms of infection clearance and functional outcomes in the treatment of periprosthetic shoulder infections.

What is known and what is new?

- Previously, non-revision procedures were recognized as tools that can be utilized in the treatment of periprosthetic infections. Revision techniques were reported to be more successful.
- The most recent studies have shown that one-stage, as opposed to two-stage, produced better results in terms of infection clearance. Non-revision procedures should be left and only be used in selected cases.

What is the implication, and what should change now?

- These findings alone are insufficient to provide new guidelines into clinical practice. The decision-making process should also consider additional aspects. Infection by definition, should be taken into account and utilized more uniformly with consensus criteria and meticulous determination of clinical significance of C. acnes. Prospective randomized trials should serve as the foundation for future research.

Methods

Studies selection

Systematic literature research was performed using PubMed (MEDLINE), ScienceDirect (Elsevier), and Google Scholar databases on September 30, 2022. The keywords used in the search were “shoulder arthroplasty infection treatment”, “shoulder arthroplasty infection revision”, “shoulder prosthesis infection treatment”, and “shoulder prosthesis infection revision”. This process incorporated a four-phase search strategy involving identification, screening, eligibility, and included, respectively. The flowchart used in the process is provided in *Figure 1*.

Following the PRISMA 2020 guidelines, three authors reviewed all the titles and abstracts (or full texts if needed) independently to reduce the risk of bias, removed duplicates, and included studies on PSIs (11). Articles were investigated even if that individual paper was selected by one author only, then re-evaluated according to inclusion criteria by three authors. Editorials, abstracts from scientific meetings, case reports, review articles and meta-analyses, series on non-operative treatment, shoulders with a follow-up of fewer than 24 months, and series without clear indications and surgical outcomes were excluded. All articles referring to surgical treatment of PSI, published between 2016 and 2022, and were written in the English language were included. In addition, references to each selected article were checked to identify any missed articles.

Data collection

After exclusions, a total of sixteen studies that met the inclusion criteria were identified for final evaluation. All articles were retrospective case series. Levels of evidence rated according to the Oxford 2011 Levels of Evidence (12).

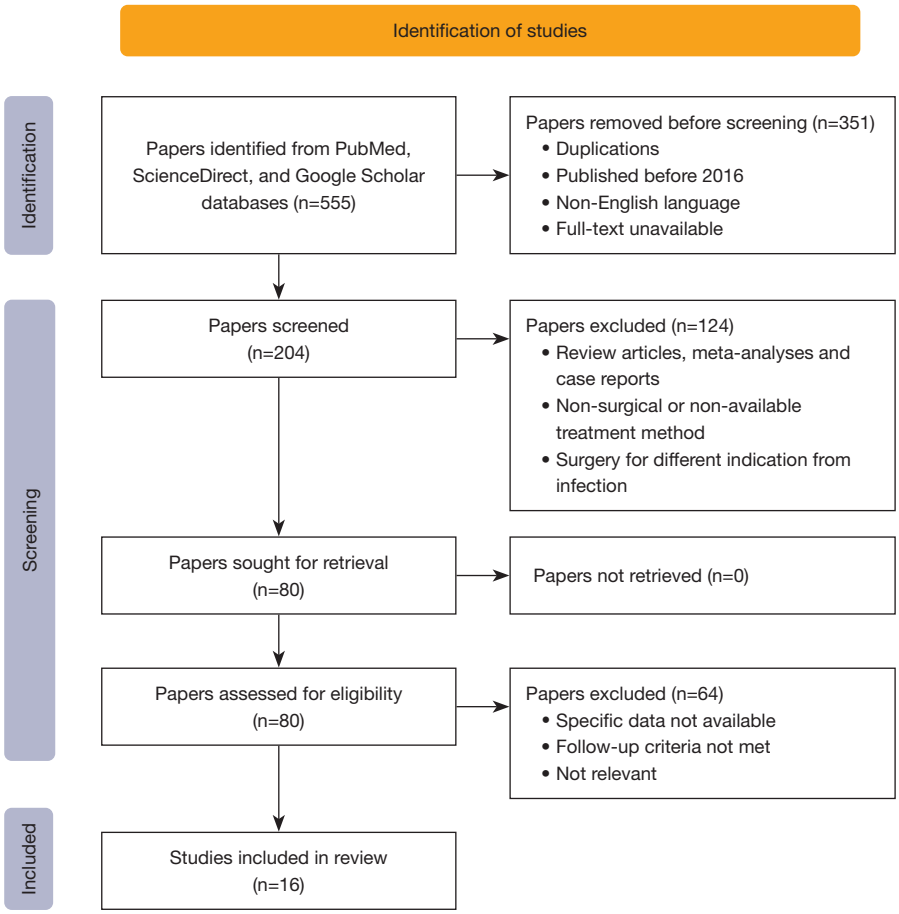

Figure 1 Flowchart outlining the process of study selection for this systematic review.

Five surgical treatment options included from the studies were; DAIR, resection arthroplasty, definitive spacer, one-stage revision, and two-stage revision. Multiple staged revisions were also identified as two-stage revisions.

Risk of bias assessment

Joanna Briggs Institute's tool of Critical Appraisal Checklist (13) was used to assess risk of bias. Clear criteria for inclusion and exclusion were questioned for studies. Infection descriptions and methods for the diagnosis of infection were assessed for validity. The studies were investigated for consecutive and complete inclusion of participants. Patient demographics, clinical information and outcomes were reviewed for clarification. Statistical analyses for each study were investigated for appropriateness. Risks of bias of each study were summarized in *Table 1*. Overall, in this systematic review, study-level risk of bias was rated low, since all questions were addressed conveniently and there were only few unclear answers with mixed variables.

Evaluation criteria

According to the treatment method, persistent infection (PI) after surgical treatment was regarded as the main unsatisfactory outcome. Shoulders that had undergone surgery for PSI and had no infection during follow-up were considered successfully treated. Additional surgeries are unrelated to PSI were also recorded.

The reviewed articles utilized several different functional scores for outcome evaluation. The most commonly available measurements; Constant and Murley Score (CMS) and forward elevation degree (FE), were recorded, pooled, and analyzed regarding differences between treatment methods.

Causative microorganisms for primary infection and re-infection were noted.

Table 1 Risk of bias assessment of included studies in the present systematic review

Authors	Clear inclusion criteria	Reliable condition measurement	Valid identification methods	Consecutive inclusion	Complete inclusion	Clear participant demographics	Clear clinical information	Clear outcomes	Clear research site information	Appropriate statistical analysis
Glanzmann *et al.* (14)	Yes	Unclear	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	Yes
Hsu *et al.* (15)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mahure *et al.* (16)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lee *et al.* (17)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Assenmacher *et al.* (18)	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Buchalter *et al.* (19)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dennison *et al.* (20)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Torrens *et al.* (21)	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sevelda *et al.* (22)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grubhofer *et al.* (23)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pellegrini *et al.* (24)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Brown *et al.* (25)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bdeir *et al.* (26)	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes
Bordure *et al.* (27)	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes
Lemmens *et al.* (28)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lo *et al.* (29)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 2 Demographics of included studies in the present systematic review

Authors	Year of publication	Levels of evidence	Number of patients	Number of shoulders	Duration of mean follow-up (months)	Design
Glanzmann *et al.* (14)	2016	4	3	3	24	R, CS
Hsu *et al.* (15)	2016	3	27	27	45	R, CS
Mahure *et al.* (16)	2016	4	9	9	63	R, CS
Lee *et al.* (17)	2017*	4	12	12	40	R, CS
Assenmacher *et al.* (18)	2017	4	34	35	48	R, CS
Buchalter *et al.* (19)	2017	4	19	19	63	R, CS
Dennison *et al.* (20)	2017	4	10	11	48	R, CS
Torrens *et al.* (21)	2018	4	21	22	24–108	R, CS
Sevelda *et al.* (22)	2018	4	14	14	70	R, CS
Grubhofer *et al.* (23)	2018	3	38	38	52	R, CS
Pellegrini *et al.* (24)	2019	3	30	30	96	R, CS
Brown *et al.* (25)	2020	3	16	16	48	R, CS
Bdeir *et al.* (26)	2021	4	15	15	83	R, CS
Bordure *et al.* (27)	2021	3	18	18	50	R, CS
Lemmens *et al.* (28)	2021	3	35	35	35	R, CS
Lo *et al.* (29)	2022*	4	38	38	33	R, CS

*, e-pub years. R, retrospective; CS, case series.

Study demographics: year of publication, scientific level, number of patients (only the included patients from the specified study), design fashion, reported CMS, and FE (*Table 2*); and patient demographics: age, gender, primary arthroplasty indication, and primary implant design (*Table 3*) were recorded. Due to the heterogeneity of the studies, there were missing data in multiple fields which could not be included in the analyses.

Statistical analysis

IBM SPSS Statistics software (version 25.0; IBM Corp., Armonk, NY, USA) was used for the database construction and the statistical analysis; all data were collected, measured, and reported with one-decimal accuracy. The mean and standard deviation comparisons were performed using unpaired *t*-tests, and 2×2 contingency tables were used to compare proportions. A P value <0.05 was considered significant.

Results

A total of 339 patients with (342 shoulders) from 16 different studies were included (14-29). *Table 2* provides demographic information for the included studies. In total, 139 of the patients were female, and 197 were male. The gender of three patients was not specified. The mean age of the patients was 67.5±3.8 years. The mean follow-up duration was 53.3±19.5 months.

Initial surgery

Initial arthroplasty indication details were obtained for 149 of 342 shoulders. Of 149 shoulders, 60 (40.2%) had a traumatic indication, 43(28.8%) had rotatory cuff arthropathy, 41 (27.5%) had osteoarthritis, and 5 (3.3%) had avascular necrosis before the initial arthroplasty surgery (*Figure 2*). The design of the initial implant was recorded for 237 of 342 shoulders. Of 237 shoulders, 108 (45.5%) had total shoulder arthroplasty (TSA), 71 (29.9%) had reverse TSA (RTSA), and 58 (24.4%) had hemiarthroplasty (HA) (*Figure 3*).

Causative microorganisms

Data regarding microorganisms that caused initial PSI

Table 3 PI rate, mean weighted final CMS, and forward elevation degrees for: DAIR, resection arthroplasty, definitive spacer, two-stage revision arthroplasty, and one-stage revision arthroplasty treatment groups

Authors	Number of shoulders	Age (years)	Mean follow up (months)	PI	PI (%)	Final CMS	FE (°)
DAIR							
Dennison *et al.* (20)	11	69.0	48.0	3	27.2	N/A	140.0
Bdeir *et al.* (26)	6	67.1	93.0	0	0.0	N/A	N/A
Lemmens *et al.* (28)	6	71.0	35.0	4	66.6	13.0	82.0
Total	23	69.0±1.4[#]	56.3±22.9[#]	7	30.4	13.0±0.0[#]	119.3±28.5[*#]
Resection arthroplasty							
Bdeir *et al.* (26)	2	67.1	40.0	0	0.0	N/A	N/A
Lemmens *et al.* (28)	4	71.0	4.0	0	0.0	12.0	45.0
Total	6	69.7±2.0[#]	36.6±2.5[#]	0	0.0	12.0±0.0[#]	45.0±0.0[#]
Definitive spacer							
Mahure *et al.* (16)	9	72.8	63.0	0	0.0	N/A	67.0
Grubhofer *et al.* (23)	4	62.0	52.0	0	0.0	35.0	N/A
Pellegrini *et al.* (24)	19	70.2	96.0	0	0.0	37.0	58.0
Bdeir *et al.* (26)	3	67.1	68.0	2	66.6	N/A	N/A
Lemmens *et al.* (28)	2	71.0	35.0	0	0.0	18.0	55.0
Total	37	69.7±3.1[#]	77.6±20.3[#]	2	5.4	35.1±5.2[#]	60.5±4.3[#]
Two-stage revision							
Glanzmann *et al.* (14)	3	68.7	24.0	0	0.0	25.0	45.0
Lee *et al.* (17)	12	69.5	40.0	0	0.0	66.0	81.0
Assenmacher *et al.* (18)	35	65.0	48.0	5	14.2	N/A	118.0
Buchalter *et al.* (19)	19	69.0	63.0	5	7.9	N/A	119.0
Torrens *et al.* (21)	22	67.5	24.0–108.0	3	13.6	34.0	78.0
Grubhofer *et al.* (23)	34	62.0	52.0	2	5.8	44.0	N/A
Pellegrini *et al.* (24)	11	66.6	96.0	0	0.0	43.0	78.0
Brown *et al.* (25)	16	69.8	48.0	4	25.0	N/A	N/A
Bdeir *et al.* (26)	4	67.1	102.0	0	0.0	N/A	N/A
Bordure *et al.* (27)	1	70.3	50.0	0	0.0	N/A	N/A
Lemmens *et al.* (28)	22	71.0	35.0	0	0.0	32.0	87.0
Lo *et al.* (29)	38	68.0	33.0	4	10.5	N/A	N/A
Total	217	67.0±4.0[#]	48.7±17.8[#]	23	10.6	41.2±10.5[#]	96.6±20.1[#]
One-stage revision							
Hsu *et al.* (15)	27	63.5	45.0	0	0.0	N/A	N/A
Sevelda *et al.* (22)	14	71.0	70.0	1	7.1	65.0	90.0
Bordure *et al.* (27)	17	70.3	50.0	1	5.8	N/A	N/A
Lemmens *et al.* (28)	1	71.0	35.0	0	0.0	42.0	120.0
Total	59	67.3±3.5[#]	52.2±10.3[#]	2	3.4	63.4±5.9[*#]	92.0±7.7[#]
All groups	342	68.4±3.3[#]	53.0±23.5[#]	34	9.9	40.5±13.7[#]	91.5±25.0[#]

*, indicates statistically significant values between different treatments; #, data are present as mean ± SD. PI, persistent infection; CMS, Constant and Murley Score; DAIR, debridement, antibiotics, and implant retention; FE, forward elevation degree; N/A, not available; SD, standard deviation.

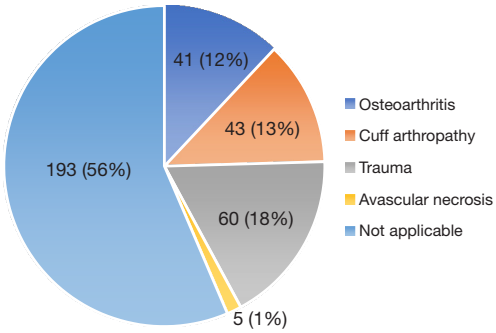

Figure 2 Indication for initial prothesis (n=342).

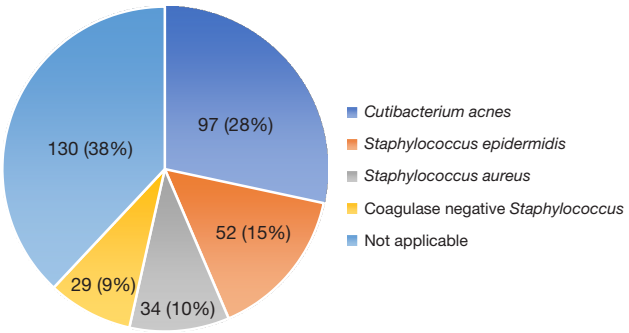

Figure 4 The proportion of cultured microorganism strains for initial infection (n=342).

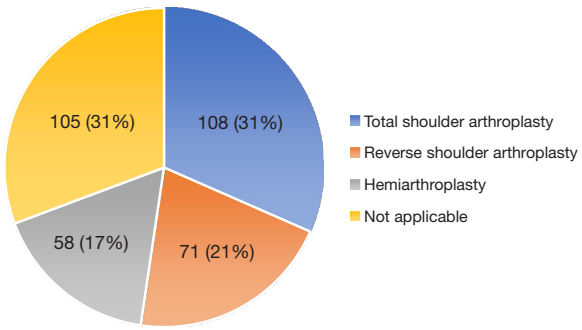

Figure 3 Initial prosthesis before the periprosthetic infection (n=342).

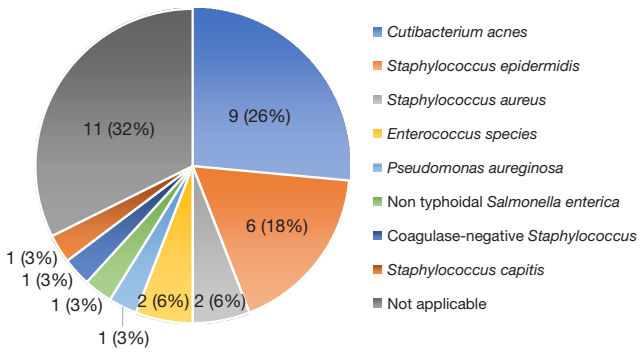

Figure 5 The proportion of cultured microorganism strains for PI in all surgical treatments of infected shoulder arthroplasty (n=34). PI, persistent infection.

were available for 221 shoulders. Of 221 shoulders, *C. acnes* was detected in 97 (43.8%) shoulders, and *Staphylococcus epidermidis* (*S. epidermidis*) was detected in 52 (23.5%) shoulders. *S. aureus* and coagulase-negative *Staphylococcus* other than *S. epidermidis* were detected in 34 (15.3%), and 29 (13.1%) shoulders, respectively, and 9 (4%) shoulders were infected with rare infectious agents (*Figure 4*).

Thirty-four (10%) of the shoulders had a PI. The microorganism responsible for the PI were reported in 23 of 34 shoulders. The most common PI agent was *C. acnes*, with nine infected shoulders (39.1%) (*Figure 5*).

Interventions for infection clearance

In total, 217 (63.4%) two-stage revisions, 59 (17.2%) one-stage revisions, 37 (10.8%) definitive spacer applications, 23 (6.7%) DAIR, and 6 (1.7%) resection arthroplasty procedures were applied.

The DAIR group had a small sample size of 23 shoulders, but had the significantly highest failure rate, with a 30.4% of PI (P=0.003), among the surgical treatment methods. The PI rate was 10.6% in the two-stage revision group, 5.4% in the definitive spacer group, and 3.4% in the one-stage revision group. There were no PIs in the resection arthroplasty group. When PIs in the treatment groups were compared, the DAIR group statistically had more failure rate than the other treatment methods (P=0.003); however, there were no statistically significant differences among the other four treatment groups (P=0.23).

Functional assessment

In 8 (50%) of the 16 studies (14,17,21-24,27,28), CMSs were assessed for functional evaluation. The American Shoulder and Elbow Surgeons (ASES) scores were assessed in the 3 of 16 (18.7%) studies (16,17,19), and the Visual Analogue Scale (VAS) scores were assessed in the 3 of 16 (18.7%) studies (15,17,24).

In the non-revision group (DAIR, resection arthroplasty, and definitive spacer), the CMS of the definitive spacer group (35.1±5.2) was significantly higher than the DAIR (13±0) and resection arthroplasty (12±0) groups (P=0.001), while there was no significant difference between the DAIR and resection arthroplasty groups (P>0.99).

The DAIR group (119.3°±28.5°) was significantly better than the other treatment groups in terms of FE (P=0.001). The two-stage revision group, one-stage revision group, definitive spacer group, and resection arthroplasty group had 96.6°±20.1°, 92.0°±7.7°, 60.5°±4.3°, 45°±0° of FE, respectively. Furthermore, the revision group (one-stage and two-stage) had statistically better FE than resection arthroplasty and definitive spacer groups (P=0.001).

The revision group had higher CMS than the non-revision group, and the one-stage revision group (63.4±5.9) had statistically higher post-operative CMS than the two-staged revision group (41.2±10.5) (P=0.001). In the non-revision group, patients who underwent the definitive spacer procedure had significantly higher CMS than those who underwent DAIR or resection arthroplasty (P=0.001).

PI rates, CMS, and FE are shown in *Table 3* in detail.

Additional surgeries

There were several additional surgical interventions performed for reasons other than infection. Surgery for aseptic loosening was performed on three shoulders in the two-stage revision group. Five patients underwent surgery for dislocation (three in a one-stage revision group and two in the two-stage revision group). Three patients in the one-stage revision group were treated for shoulder stiffness; two underwent surgical release, and one was treated with manipulation under anesthesia. Furthermore, two patients were observed conservatively for greater tuberosity fracture in the one-stage revision group.

Discussion

Infection is one of the most challenging complications after shoulder arthroplasty (30,31). However, there are no prospective, randomized controlled studies in the literature, and treatment preferences are made using level three and four studies or knee and hip arthroplasty guidelines available (32).

In this study, a systematic review of the most recent studies published on the surgical treatment of PSI between 2016–2022 was made. We believe including only the most recent literature will reflect the outcomes corresponding to the current treatment progression.

Our study showed that DAIR was insufficient to control PSI, with a PI rate of 30.4%. At the same time, there was no significant difference regarding PI among the other four surgical treatment methods [resection arthroplasty (0%), definitive spacer application (5.4%), and one-stage (3.4%) or two-stage (10.6%) revision surgery] (P=0.23). The insufficient number of patients in some groups and the highly variable number of patients in the treatment groups may explain the inability to obtain a significant difference regarding PI rates. For instance, 217 patients were treated with two-staged revision, while only six were treated with resection arthroplasty.

It was observed that resection arthroplasty was the most successful treatment method in PSI eradication with a 0% PI rate. Interestingly, it was the worst treatment method in terms of FE and one of the two worst treatment methods in terms of CMS. Considering that this method was evaluated in six patients from only two studies and used mostly as a salvage procedure, it can be said that although the PI rate is low, resection arthroplasty cannot be regarded as a principal treatment method for PSI (26,28). In addition, the different results in functional scores can be explained by the fact that it was evaluated in a small number of patients. However, resection arthroplasty can be considered as an alternative method in patients where infection control cannot be achieved, or re-implantation can not be performed (33,34).

Another method used in surgical treatment is antibiotic-loaded spacers. This method can be used as a definitive treatment or as part of a two-stage revision surgery (10,16). Definitive spacers were primarily preferred in patients with severe comorbidities, bony deformities, or defects that did not allow reconstruction (16). The definitive spacer group can be regarded as the best among the non-revision procedures in terms of functional evaluations (CMS, FE) and just below revision procedures (one-stage and two-stage revision) except for the unexpectedly high reported mean FE (119.3°±28.5°) of the DAIR group.

Our study showed that, regarding PSI clearance, revision surgeries (one-stage or two-stage) were considered more successful than other treatment methods, excluding resection arthroplasty, similar to previous review articles (6,35). It was also demonstrated that the one-stage revision surgery is superior to the two-stage surgery in terms of PI and CMS, and the two methods have comparable results in terms of FE.

Considering studies related to revision surgery, it is not

possible to objectively state that one of these two methods is superior to the other due to some biases such as the timing of the revision surgery, the preference of the patient, the soft tissue/osseous appearance during the surgery, and whether the microorganism diagnosis is made before the surgery (22,27,28). However, it can be said that choosing the one-stage revision, if feasible, is more likely to result in better outcomes regarding functional results and infection clearance.

One of the most decisive factors in choosing to perform revision surgery in one or two stages is the isolation of the infectious agent before surgery. Surgeons tend to perform two-stage surgery, especially when the infectious agent is uncertain. However, two-stage revision has tended to increase morbidity and the cost of surgery (15). Surgeons prefer to perform two-stage revision surgery, especially when the infectious agent is uncertain. Although the duration of antibiotic therapy after one-stage surgery was more prolonged, PI rates and functional results were comparable in some studies (7,15,36,37). On the other hand, George *et al.* reported that clinical results after one-stage revision surgery were better than the two-stage revision surgery. Still, there was no significant difference between clinical improvements after the two surgeries (38).

Ruditsky *et al.* compared one-stage versus two-stage revision arthroplasty in an infectious setting and found that although one-stage revisions provided superior infection clearance, functional outcome improvements from pre-operative to final were better in two-stage revisions, and both treatment strategies were effective. In their study, there was no statistical comparison and it must be taken into consideration that the mentioned improvement does not indicate better outcomes, as final outcomes were more important to evaluate functional results. In detail, final FE, external rotation, abduction, and CMS were higher in the one-stage, ASES score and Simple Shoulder Test score were higher in the two-stage group (35). These are mostly correlated with our results and we believe they are inconclusive to suggest two-stage revision as an effective method in the management of PSI.

Another factor as important as the surgical method in the success of the treatment is the antibiotic resistance of the infectious agent. Stone *et al.* reported that one (2%) methicillin-resistant *S. aureus* (MRSA) was detected in the one-stage revision group. In contrast, 3 (16%) MRSA were detected in the two-stage revision group in their study, which showed that there was less PI rate after one-stage revision compared to the two-stage revision (39).

Although it was not mentioned in our study because no standard data could be obtained, the type of implant used after a revision surgery is significant, especially regarding functional results. In recent studies, RTSA has been used more frequently, especially in patients with supraspinatus tendon problems, and better functional outcomes have been reported than TSA (22,39,40).

In the current review, *C. acnes* was the most common causative microorganism of PSI. *C. acnes* (formerly *Propionibacterium acnes*) is an anaerobic bacteria that is capable of forming a biofilm to escape from host defense mechanisms (10). It commonly resides in the hair follicles and is the most common isolated pathogen in both primary and persistent PSIs. Whether this finding with *C. acnes* represents contamination or evidence of deep infection is a hot topic of debate as PSIs caused by *C. acnes* rarely manifest as obvious infections and unexpected positive cultures are not equivalent to clinically relevant infections (41,42). This was also an obscuring factor in the referenced articles about the definition of infection. Furthermore, regarding this issue, Hodakowski *et al.* noted that definition of infection is variable between different studies and argued that diagnosis and treatment of PSIs are largely variable among different hospitals (43). This was also valid for the studies investigated in this review. It is important to note that the PSI definition would become more uniform after 2018 PJI meeting consensus on criteria for the diagnosis of PSI, even this clarification is still in its early phases (44). Ellsworth *et al.* suggested utilizing a ten-day culture incubation method would be adequate to diagnose PSI which otherwise will take longer durations. They concluded that prospective studies are crucial for the appreciation of the clinical significance of *C. acnes* (45). We strongly agree that this domain needs to be illuminated with well-designed studies before reaching any conclusion.

The main strong aspect of this review was including only the most current publications after 2016. This filtering allowed us to evaluate the latest surgical treatment options and preference rates. It is important to note that apart from the indisputable main results, most of the secondary conclusions were limited by missing data and biases. Furthermore, since there were many heterogeneous data, such as the time gap before surgical treatment of PSI, the algorithm used for infection diagnosis, and the patients' comorbidities, a detailed evaluation could not be made about the effect of preoperative variables on treatment selection and outcomes. These limitations occurred by the nature of this study. Also, in all studies included, there is still an

indisputable risk of infection reoccurrence after the follow-up period. We only included studies that have a minimum two years of follow-up to minimize the effect of this bias.

Conclusions

Overall, the most current studies in the literature demonstrated that revision procedures were able to produce superior outcomes compared to non-revision procedures both from infectious and functional perspectives. Among revision procedures, one-stage revision arthroplasty yielded better infection clearance than two-stage revision arthroplasty. Yet, these facts alone are insufficient for the implementation of new guidelines into clinical practice. Other variables, patient-specific factors, the timing of infection and surgery, and the perioperative status of osseous structures and soft tissues should all be taken into account in the decision-making process. Future research should be based on prospective randomized studies.

Acknowledgments

Funding: None.

Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editor (Prashant Meshram) for the series "Controversies in Shoulder Surgery and Algorithmic Approach to Decision Making" published in *Annals of Joint*. The article has undergone external peer review.

Reporting Checklist: The authors have completed the PRISMA reporting checklist. Available at https://aoj.amegroups.com/article/view/10.21037/aoj-22-48/rc

Peer Review File: Available at https://aoj.amegroups.com/article/view/10.21037/aoj-22-48/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://aoj.amegroups.com/article/view/10.21037/aoj-22-48/coif). The series "Controversies in Shoulder Surgery and Algorithmic Approach to Decision Making" was commissioned by the editorial office without any funding or sponsorship. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/aoj-22-48
Cite this article as: Aksoy T, Yilmaz A, Beydemir A, Yataganbaba A, Huri G. Comparison of surgical treatment options in periprosthetic shoulder infections: a systematic review from 2016 to 2022. Ann Joint 2023;8:20.