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REVIEW ARTICLE

Surgical treatment of infected shoulder arthroplasty. A systematic review

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Abstract
Purpose To investigate the best surgical management of infected shoulder arthroplasty.
Methods A literature review from 1996 to 2016 identified 15 level IV studies that met inclusion criteria. Persistent infection (PI) was considered as treatment failure. Success was regarded as the absence of symptomatic PI without necessity for further treatment. Surgical outcomes were reported according to the mean weighted Constant and Murley score (CMS) for each treatment group.
Results Overall, 287 patients (146 males/141 females) were identified at a mean follow-up of 50.4 (range 32–99.6) months. The PI in the whole population was 11.5%. The pooled mean CMS, available for 218 patients, was 39 ± 13. Twenty-seven patients (9.4%) were treated with debridement (PI 29.6%, CMS 41 ± 12), 52 patients (18.1%) with resection arthroplasty (PI 11.5%, CMS 29 ± 16), 33 patients (11.5%) with permanent spacers (PI 6.1%, CMS 31 ± 14), 98 patients (34.2%) with two-stage revisions (PI 14.3%, CMS 42 ± 12) and 77 patients (26.8%) with one-stage revisions (PI 3.9%, CMS 49 ± 11).

Debridement showed the highest PI rate (29.6%) and one-stage revisions reported the lowest PI rate (3.9%). Resection arthroplasty and spacers showed the poorest CMS when compared to the other procedures ($p \leq 0.0001$). The debridement PI rate was significantly higher than almost any other procedure. CMS was significantly higher in patients undergoing revision compared to non-revision procedures (45 ± 12 vs.

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35 ± 14) ($p < 0.0001$). One-stage revisions achieved significantly better results in terms of the PI rate compared to two-stage revisions ($p = 0.0223$), but not in terms of CMS.
Conclusion Debridement showed the highest PI rate (29.6%) and should not be recommended for the management of infected shoulder arthroplasty. Revisions reported better functional outcomes compared to non-revision procedures. The presence of a significantly lower PI rate with comparably high mean CMS values suggests that one-stage (where technically applicable) could be superior to two-stage revisions.

Unfortunately, well-designed randomized controlled trials using validated patient-based outcomes are lacking in this field.

Level of evidence: Systematic Review of level IV studies, Level IV

Keywords Arthroplasty · Infection · Shoulder · Surgical treatment · Systematic review

Introduction

In 1893 Jules Emile Péan, after debriding tuberculous arthritis of the shoulder in a 37-year-old baker, implanted the first shoulder prosthesis. Unfortunately, the infection recurred, and the prosthesis was removed after only two years [1].

Since then there has been a steady evolution in shoulder arthroplasty with improvement and refinement in surgical technique and implant design, providing patients with pain free functionality of their shoulders. Despite advances in the field, it is virtually impossible to completely eliminate the risk of infection in shoulder replacements.

According to the literature, the incidence of infection after total shoulder arthroplasty ranges between 0 and 3.9% for total shoulder arthroplasty and up to 15% in revision prosthesis [2–6]. The incidence rate ranges between 2 and 18.8% for reverse shoulder arthroplasty [7, 8].

Staphylococcus aureus, Staphylococcus epidermidis, and Propionibacterium acnes are the most commonly isolated organisms from the cultures of post-operative shoulder infections [6, 9].

Available treatment options for postoperative shoulder infections include: irrigation and debridement, removal of the prosthesis alone (resection arthroplasty), removal of the prosthesis and replacement with an antibiotic-loaded cement (spacer), spacer followed by a following revision (two-stage revision), one-stage revision, removal of the prosthesis and arthrodesis, chronic suppression of infection with antibiotics, and even amputation. Of these options, the most common treatments are revision arthroplasty, spacer, and resection arthroplasty [9–11]. Which treatment is the most successful in irradicating the infection while providing better outcomes, however, still remains an open question.

Since there is still no consensus on the surgical treatment of infected shoulder prosthesis, the purpose of this systematic review of the literature was to investigate which procedure shows the highest success rate and best functional outcomes.

Material and methods

Studies selection

A literature research of PubMed, Google Scholar, and Cochrane Reviews computerized databases was performed using the keywords "shoulder", "prosthesis", "arthroplasty", and "infection", in combination with "surgery", "surgical treatment", and "revision" in order to identify all papers, including other reviews, reporting surgical outcomes of the treatment of infected shoulders after shoulder arthroplasty. In addition, we extended the research to the reference list of all relevant articles. In total, 24 studies were identified that fit the criteria above.

Two independent reviewers then performed a more refined review of the 24 identified studies in the literature search utilizing the following inclusion and exclusion criteria (they referred to the abstract or the full text article when required) as well as the PRISMA guidelines [12].

All published series (1) regarding surgical treatment of infection after shoulder arthroplasty (primary or revision implants), (2) written in the period from 1996 to 2016, (3) written in English, were included.

Exclusion criteria were: (1) case reports, (2) studies reporting non operative management, (3) a minimum follow-up less than 24 months, and (4) not clearly reporting re-infection rate and post-operative clinical outcomes.

Fifteen studies (15 papers) met the criteria and were reviewed [4, 11, 13–25]. These articles were all published between 2002 and 2016. There were no randomized controlled trials (RCTs) or prospective controlled studies. All included studies except two (a retrospective case control study by Verhelst et al. [25] and a prospective case series by Strickland et al. [24]) were retrospective case series.

Demographics of included studies are summarized in Table 1.

Five different surgical treatment groups were identified: debridement, resection arthroplasty, spacer, one-stage revision, and two-stage revision. It is important to note that all of these surgical treatment options were performed after surgical treatment-specific intravenous antibiotic therapy (guided by peri-operative culture's antibiogram) was established.

Evaluation criteria

Different authors used different evaluation criteria to describe outcomes of treatment in the reviewed articles. Success was

Table 1 Demographics of included studies in the present systematic review

Demographics						
Authors	Year of publication	Scientific level	Number of patients*	Duration of mean follow-up (months)	Design	CMS reported
Coste et al.	2004	4	34	32.0	R	yes
Cuff et al.	2008	4	17	43.0	R	no
Ghijselings et al.	2013	4	17	56.4	R	yes
Grosso et al.	2012	4	17	35.8	R	no
Ince et al.	2005	4	9	69.6	R	yes
Jaquot et al.	2015	4	32	36.0	R	yes
Klatte et al.	2013	4	35	69.6	R	yes
Mileti et al.	2004	4	4	88.8	R	no
Ortmaier et al.	2014	4	18	73.7	R	yes
Rispoli et al.	2007	4	13	99.6	R	no
Romano et al.	2012	4	43	41.0	R	yes
Seitz and Damacen	2002	4	5	57.6	R	no
Strickland et al.	2008	4	19	35.0	Prosp	no
Verhelst et al.	2011	3	21	46.4	R	yes
Weber et al.	2011	4	9	48.0	R	yes

CMS Constant and Murley score, *R* retrospective, *pros* prospective

regarded as the absence of a symptomatic persistent infection (PI) without the necessity of further treatments. Surgical functional outcomes were evaluated by referring to the mean weighted Constant and Murley score (CMS) [26] for each identified treatment group.

Statistical analysis

Statistical evaluation was performed using MedCalc (MedCalc software bvba, Ostend, Belgium). Due to the incompleteness of the data, particularly regarding the treatment subgroups, follow-up was expressed exclusively with the mean value. Regarding the CMS, in order to allow statistical comparison, the standard deviation was extracted from the text and, when it was not available, it was calculated from the range (range/4). The categorical data regarding reinfections was expressed as an absolute number and percentage. Statistical comparison between the CMS of the different treatment groups was performed with an unpaired t-test, while comparison between the proportions of PI patients were compared using a 2×2 contingency table. The level of significance was set at $p < 0.05$.

Results

Overall, 287 patients (146 males, 141 females) were included in the systematic review. The mean follow-up of the whole population was 50.4 (range 32–99.6) months.

Due to the heterogeneity and low quality of the included studies, it was impossible to pool and standardize the demographic, surgical, and infection data from the whole population and each group. Because of this, it was not possible to determine if there were any subgroups influencing the infection rate for the whole population. However, from the available data the most frequent indication for primary infected arthroplasty was shoulder OA followed by a proximal humerus fracture. The type of implant used initially was available only for 170 of the 287 patients (64 hemi-arthroplasty, 29 total shoulder arthroplasty, 73 reverse shoulder arthroplasty, and four tumoral resection implants). The most frequently cultured pathogens from peri-operative samples were Staphilococcus epidermidis [4, 11, 17, 18, 22] and the Propionibacterium species [15, 17, 20].

Twenty-seven patients (9.4%) were treated with debridement, 52 patients (18.1%) with resection arthroplasty, 33 patients (11.5%) with a permanent spacer, 98 patients (34.2%) with a two-stage revision, and 77 patients (26.8%) with a one-stage revision.

The types of implants used for revisions were not available for the study by Coste et al. [4]. Considering the other included studies, the breakdown for implants used in two-stage revisions were 23 hemi-arthroplasty, six total shoulder arthroplasty, and 59 reverse shoulder arthroplasty. Regarding the use of one-stage revision procedures, 38 were hemi-arthroplasty, nine were total shoulder arthroplasty, and 27 were reverse shoulder arthroplasty.

The total number of PI in the whole population was 33, with an overall failure rate of 11.5%. The pooled mean CMS available for 218 patients was 39 ± 13.

The PI rate and mean weighted final CMS was summarized for each treatment group in Table 2 and globally in Fig. 1.

If the outcomes of the different treatments were compared in terms of failure, debridement showed the highest PI rate (29.6%), and one-stage revisions reported the lowest PI rate (3.9%). The PI rate of debridement was significantly higher than any other procedure ($p \leq 0.05$) except one. Although not statistically significant, when comparing debridement and two-stage revisions in terms of PI rate, the p value was still close to being significant ($p = 0.637$).

Regarding functional results, resection arthroplasty and spacers showed the poorest CMS when compared to other procedures ($p \leq 0.0001$). CMS was significantly higher in patients undergoing (two-stage and one-stage) revision compared to non-revision procedures (debridement and spacer and resection arthroplasty) (45 ± 12 vs 35 ± 14) ($p < 0.0001$).

One-stage revision achieved significantly better results in terms of PI rate compared to two-stage revision ($p = 0.0223$) but not in terms of CMS.

Discussion

The most important findings of the present systematic review were that the debridement PI rate was significantly higher than almost any other procedure and that revision reported better functional outcomes compared to non-revision procedures.

Debridement was found to have the highest PI rate (29.6%) in the treatment of periprosthetic shoulder infections. In addition, the functional results were reported to be less satisfactory than other methods used in this systematic review. There is no consensus about proper debridement protocol and about the association of polyethylene exchange. The results of this procedure were reported to be unpredictable and the increased possibility of further surgeries proves to be a major disadvantage with this approach. Moreover, timing of debridement is controversial. Although, early serial washouts (<2 weeks post-operatively) were reported to eradicate infection and preserve motion, [4] the high risk of PI with debridement should be kept in mind [20]. Debridement in late infections (>12 months) was shown to be ineffective [4]. Based on these results, debridement with retention of the prosthesis is not recommended in the treatment of infected shoulder arthroplasty.

Resection arthroplasty (removing the implant and resecting the humeral head alone) or antibiotic loaded spacers were found to have a high success rate in infection treatment (mean PI 11.5% and 6.1%, respectively). However, functional results for both approaches were noted to be disappointing in our review (mean CMS 29 ± 16 and 31 ± 14, respectively), as they demonstrated the poorest functional outcomes compared to other treatments ($p \leq 0.0001$). Rispoli et al. [21] found high rates of patient dissatisfaction (89%) when treated with resection artrhroplasty, although they reported no PI with a mean of 8.2-year follow-up. Therefore, it was concluded that pain relief could not be guaranteed with this procedure. Even though permanent spacers have poor functional outcomes and patient satisfaction, this procedure was found to have a high success rate in the treatment of infection. Permanent spacers still remain viable options as a salvage procedure for PI unresponsive to other treatments and for low-demanding patients who are medically poor candidates for complex revision surgeries.

Two-stage and one-stage revisions showed superior functional outcomes compared to non-revision procedures. Different revision implant designs (hemiarthroplasty, total shoulder prosthesis and reverse shoulder prosthesis) were used in individual studies. It was not possible to determine if there was any difference in the functional outcome between patients treated with primary, revision, or reverse implants because almost all included studies reported mean CMS values for one-stage or two-stage revisions without differentiating different implants. However, there is a prevalent use of reverse shoulder arthroplasty in two-stage revision procedures. This could be driven by the necessity for an extensive release needed in the case of soft-tissue retractions which is very commonly seen after a previous surgery followed by shoulder immobilization, as often occurs in two-stage procedures. Theoretically, this approach only requires the deltoid muscle to be protected, making adequate debridement easier [13–15, 17, 18, 20, 22]. High rate of complications with two-stage revision was reported in several studies. These complications include periprosthetic fracture, instability, tuberosity fracture, and non-union [20, 24]. The advantages of one-stage revision include reduced costs, single hospital stay, better functional outcomes, and global shorter antibiotic duration. The limit of this approach is that some prerequisites, available only in big hospitals specialized in prosthetic surgery, are mandatory: detecting the infecting organism by pre-operative joint aspiration, one-stage revision arthroplasty with extensive drebidment plus organism specific antibiotic cement, and post-operative prolonged antibiotic treatment (based on clinical findings and infection markers such as the level of C reactive protein) [15, 16, 18].

Identifying the patient and procedure-specific risk factors for periprosthetic shoulder infections is of great importance. Due to the heterogeneity of the included studies, it was not possible to determine if there were any subgroups influencing the infection rate for the whole population in the present systematic review.

The only large study included in the present review where infection-influencing factors were statistically analyzed was the one published by Coste et al. [4]. In this study, authors identified three diagnoses before the primary surgery with

Table 2 Persistent infection rate and mean weighted final Constant and Murley score (CMS) for: (a) debridement plus polyethylene exchange treatment group, (b) resection arthroplasty treatment group, (c) permanent spacer treatment group, (d) two-stage revision arthroplasty treatment group, and (e) one-stage revision arthroplasty treatment group

Authors	Patients	Mean follow-up (months)	Persistent infection	% persistent infection	Final Constant	DS
(a) Debridement						
Coste et al.	8	32.0	1	12.5	27	NA
Ghijselings et al.	1	56.4	0	0.0	14	±0
Jaquot et al.	13	36.0	6	46.0	51	±12
Romano et al.	5	43.2	1	20.0	43	NA
Total	27	36.9	8	29.6	41	±12
(b) Resection arthroplasty						
Coste et al.	10	32.0	3	30.0	30	NA
Ghijselings et al.	8	43.8	1	12.5	28	±19
Jaquot et al.	3	36.0	1	33.0	27	NA
Ortmaier et al.	4	73.7	0	0.0	17	±1[a]
Rispoli et al.	13	99.6	0	0.0	NA	NA
Romano et al.	6	42.0	0	0.0	32	NA
Verhelst et al.	3	46.8	1	33.0	38	±10
Weber et al.	5	48.0	0	0.0	33	±4[a]
Total	52	56.2	6	11.5	29	±16
(c) Spacer						
Coste et al.	3	32.0	0	0.0	38	NA
Ghijselings et al.	5	64.8	0	0.0	21	±13
Jaquot et al.	3	36.0	1	33.0	29	NA
Ortmaier et al.	1	73.7	0	0.0	42	±0
Romano et al.	15	36.0	1	6.4	34	NA
Verhelst et al.	6	46.8	0	0.0	26	±18
Total	33	43.4	2	6.1	31	±14
(d) 2-Stage revision						
Coste et al.	10	32.0	4	40.0	35	NA
Cuff et al.	10	43.0	0	0.0	NA	NA
Ghijselings et al.	3	68.3	0	0.0	23	±16
Jaquot et al.	14	36.0	0	0.0	46	±14[a]
Mileti et al.	4	88.8	0	0.0	NA	NA
Ortmaier et al.	12	73.7	3	25.0	52	±10[a]
Romano et al.	17	45.6	0	0.0	38	NA
Seitz and Damacen	5	57.6	0	0.0	NA	NA
Strickland et al.	19	35.0	7	36.8	NA	NA
Weber et al.	4	48.0	0	0.0	40	±8[a]
Total	98	47.1	14	14.3	42	±12
(e) 1-Stage revision						
Coste et al.	3	32.0	0	0.0	66	NA
Cuff et al.	7	43.0	0	0.0	NA	NA
Grosso et al.	17	35.8	1	5.9	NA	NA
Ince et al.	9	69.6	0	0.0	34	±19
Jaquot et al.	5	69.6	0	0.0	53	±5
Klatte et al.	35	36.0	2	5.7	51	±10[a]
Ortmaier et al.	1	73.7	0	0.0	23	±0
Total	77	43.0	3	3.9	49	±11

NA not applicable

[a] standard deviation calculated from range

greater risk of infection: sequelae of fracture, revision arthroplasty, and avascular necrosis following radiotherapy. Moreover, they pointed out how persistent infection rates after revision are significantly lower for acute infections (16%) compared to subacute/chronic ones (33%), with comparable post-operative functional outcomes. In a recent multicentric prognostic study including 3096 patients, Richards et al. [27] found that the risk of infection was lowered with age (with every 1-year increase in age, a 5% of lower risk). Male patients are also at greater risk (2.59 times; 95% CL, 1.25–5.31). Patients undergoing primary reverse shoulder arthroplasty were found to have a 6.11 times (95% Cl, 2.65–14.07) greater risk of infection compared with patients having primary unconstrained total shoulder arthroplasty. Additionally, traumatic arthroplasties carry a 2.98 times (95% Cl, 1.15–7.74) greater risk for infection than elective arthroplaties.

Regarding type of pathogen as a result influencing factor, once again the heterogeneity of the included studies did not allow us to trace any conclusion. For reinfection rates after a revision shoulder arthroplasty, Grosso et al. [15] showed that almost 50% were sustained by Propionibacterium acnes. Singh et al. [28] in a huge case series with a 33 year follow-up period, found that Staphylococcus and Propionibacterium were the most common organisms associated with deep periprosthetic shoulder infections. Propionibacterium acnes usually produces a low-virulence periprosthetic infection and more aggressive prophylaxis targeting this bacteria was recommended in patients at higher risk. Gobarty et al. [29] suggested treating shoulder prostheses with osteolysis and glenoid component loosening as if they were infected with Propioinibacterium acnes until cultures prove otherwise. Postacchini et al. [30] reported a high risk of infection (3.7%) following reverse shoulder arthroplasty in patients with rheumatoid arthritis and suggested the administration of antibiotics one or more days before surgery as well as the use of antibiotic-loaded bone cement in these patients. Maier et al. [31] found a severe vitamin D deficiency in patients with periprosthetic joint infection and suggested vitamin D supplementation as a possible way to lower this risk.

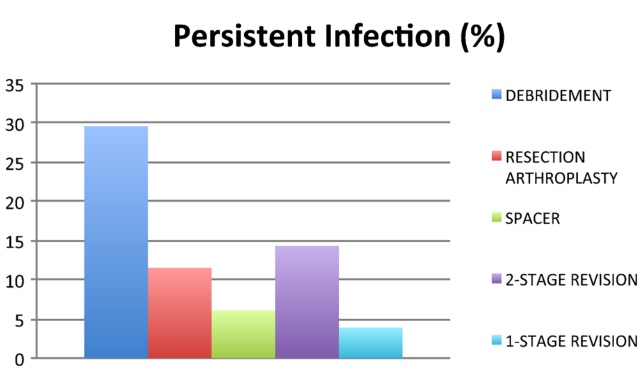

Fig. 1 Persistent infection (PI) rate after different surgical treatment of infected shoulder arthroplasty

Hackett et al. [10] proposed a classification system for periprosthetic shoulder infections that was divided into four stages according to the "time period of infection". Type I was a periprosthetic infection with positive cultures at the time of treatment. Organism specific antibiotic treatment and close observation was recommended. Type II was acute infections (<30 days of surgery) and surgical debridement and retention of the prosthesis was recommended. For acute chronic infections (>30 days after the surgery), surgical debridement with retention of the prosthesis or two-stage treatment with an antibiotic spacer was recommended. In chronic infections, surgical debridement with implant removal, a temporary antibiotic spacer and delayed reimplantation was recommended.

Saltzman et al. [9] proposed a different treatment algorithm for patients with painful shoulder arthroplasty. He suggested removal of the prosthesis, intra-operative frozen sections and cultures following a thorough pre-operative evaluation. If no clinical signs and microscopic evaluation (>5 PMNs/HPF in >1 specimens) of infection were present, a single stage revision with antibiotic impregnated cement and antibiotic therapy was recommended. In the setting of positive clinical signs or microscopic evaluation of infection, a two-stage revision with either reverse shoulder arthroplasty (rotator cuff not intact) or total shoulder/hemiarthroplasty (rotator cuff intact), following the temporary antibiotic impregnated spacer with six weeks of antibiotic therapy, was recommended as the treatment of choice. In frail or elderly patients, resection arthroplasty was advised.

Weber et al. [11] performed a retrospective analysis and literature review regarding the management of infected shoulder prostheses. It was concluded that pre-operative aspiration was crucial for organism identification to allow organism-specific antibiotic treatment, which might improve infection eradication rates.

The results of the present systematic review should be analyzed taking into consideration the following limits. CMS was not the method used to assess the functional outcome in all studies. Some studies lacked a standard antibiotic therapy protocol, which makes comparison between them difficult. We excluded studies with a minimum follow-up less than 24 months because late onset periprosthetic joint infection usually occurs two years post-operatively, as pointed out in a recent current concept review by Shahi et al. [32]. One-stage revision shoulder arthroplasty is usually performed in super-specialized centers with dedicated surgical theaters and specialized departments for infected arthroplasty treatment [16, 18]. The results of patients treated in this way in such a specialized environment could have influenced the results of this review.

Conclusion

Debridement showed the highest PI rate (29.6%) and should be not recommended as a treatment method for patients with infected shoulder arthroplasty. Revision reported better functional outcomes compared to non-revision procedures. The presence of a significantly lower PI rate with a comparably high mean CMS value suggests that one-stage (where technically applicable) could be superior to two-stage revisions.

Unfortunately, well-designed randomized controlled trials using validated patient-based outcome measurements are lacking in this field.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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References

1. Lugli T (1978) Artificial shoulder joint by Pean (1893): the facts of an exceptional intervention and the prosthetic method. Clin Orthop Relat Res 133:215–218
2. Cofield RH, Chang W, Sperling JW (1999) Complications of shoulder arthroplasty. In: Iannotti JP, Sperling JW (eds) Disorders of the shoulder: diagnosis and management. Lippincott Williams & Wilkins, Philadelphia, PA, USA
3. Cofield RH, Edgerton BC (1990) Total shoulder arthroplasty: complications and revision surgery. Instr Course Lect 39:449–462
4. Coste JS, Reig S, Trojani C, Berg M, Walch G, Boileau P (2004) The management of infection in arthroplasty of the shoulder. J Bone Joint Surg Br 86(1):65–69
5. Lettin AW, Copeland SA, Scales JT (1982) The Stanmore total shoulder replacement. J Bone Joint Surg Br 64(1):47–51
6. Sperling JW, Kozak TK, Hanssen AD, Cofield RH (2001) Infection after shoulder arthroplasty. Clin Orthop Relat Res 382:206–216
7. Jacquot N, Chuinard CH, Boileau P (2006) Results of deep infection after a reverse shoulder arthroplasty. In: Walch G, Boileau P, Molé D, Favard L, Lévigne C, Sirveaux F (eds) Reverse shoulder arthroplasty: clinical results, complications, revision. SAURAMPS Medical, Montpellier, France, pp 307–312
8. Swanson AB, de Groot Swanson G, Sattel AB, Cendo RD, Hynes D, Jar-Ning W (1989) Bipolar implant shoulder arthroplasty. Long-term results. Clin Orthop Relat Res 249:227–247
9. Saltzman MD, Marecek GS, Edwards SL, Kalainov DM (2011) Infection after shoulder surgery. J Am Acad Orthop Surg 19(4): 208–218
10. Hackett DJ, Jr., Crosby LA (2013) Evaluation and treatment of the infected shoulder arthroplasty. Bull Hosp Joint Dis 71(Suppl 2):88–93
11. Weber P, Utzschneider S, Sadoghi P, Andress HJ, Jansson V, Muller PE (2011) Management of the infected shoulder prosthesis: a retrospective analysis and review of the literature. Int Orthop 35(3):365–373. doi:10.1007/s00264-010-1019-3
12. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 339:b2535. doi:10.1136/bmj.b2535
13. Cuff DJ, Virani NA, Levy J, Frankle MA, Derasari A, Hines B, Pupello DR, Cancio M, Mighell M (2008) The treatment of deep shoulder infection and glenohumeral instability with debridement, reverse shoulder arthroplasty and postoperative antibiotics. J Bone Joint Surg Br 90(3):336–342. doi:10.1302/0301-620X.90B3.19408
14. Ghijselings S, Stuyck J, Debeer P (2013) Surgical treatment algorithm for infected shoulder arthroplasty: a retrospective analysis of 17 cases. Acta Orthop Belg 79(6):626–635
15. Grosso MJ, Sabesan VJ, Ho JC, Ricchetti ET, Iannotti JP (2012) Reinfection rates after 1-stage revision shoulder arthroplasty for patients with unexpected positive intraoperative cultures. J Shoulder Elbow Surg 21(6):754–758. doi:10.1016/j.jse.2011.08.052
16. Ince A, Seemann K, Frommelt L, Katzer A, Loehr JF (2005) One-stage exchange shoulder arthroplasty for peri-prosthetic infection. J Bone Joint Surg Br 87(6):814–818. doi:10.1302/0301-620X.87B6.15920
17. Jacquot A, Sirveaux F, Roche O, Favard L, Clavert P, Mole D (2015) Surgical management of the infected reversed shoulder arthroplasty: a French multicenter study of reoperation in 32 patients. J Shoulder Elbow Surg 24(11):1713–1722. doi:10.1016/j.jse.2015.03.007
18. Klatte TO, Junghans K, Al-Khateeb H, Rueger JM, Gehrke T, Kendoff D, Neumann J (2013) Single-stage revision for peri-prosthetic shoulder infection: outcomes and results. Bone Joint J 95-B(3):391–395. doi:10.1302/0301-620X.95B3.30134
19. Mileti J, Sperling JW, Cofield RH (2004) Reimplantation of a shoulder arthroplasty after a previous infected arthroplasty. J Shoulder Elbow Surg 13(5):528–531. doi:10.1016/S1058274604000862
20. Ortmaier R, Resch H, Hitzl W, Mayer M, Stundner O, Tauber M (2014) Treatment strategies for infection after reverse shoulder arthroplasty. Eur J Orthop Surg Traumatol 24(5):723–731. doi:10.1007/s00590-013-1251-9
21. Rispoli DM, Sperling JW, Athwal GS, Schleck CD, Cofield RH (2007) Pain relief and functional results after resection arthroplasty of the shoulder. J Bone Joint Surg Br 89(9):1184–1187. doi:10.1302/0301-620X.89B9.19464
22. Romano CL, Borens O, Monti L, Meani E, Stuyck J (2012) What treatment for periprosthetic shoulder infection? Results from a multicentre retrospective series. Int Orthop 36(5):1011–1017. doi:10.1007/s00264-012-1492-y
23. Seitz WH, Jr., Damacen H (2002) Staged exchange arthroplasty for shoulder sepsis. J Arthroplasty 17(4 Suppl 1):36–40
24. Strickland JP, Sperling JW, Cofield RH (2008) The results of two-stage re-implantation for infected shoulder replacement. J Bone Joint Surg Br 90(4):460–465. doi:10.1302/0301-620X.90B4.20002
25. Verhelst L, Stuyck J, Bellemans J, Debeer P (2011) Resection arthroplasty of the shoulder as a salvage procedure for deep shoulder infection: does the use of a cement spacer improve outcome? J Shoulder Elbow Surg 20(8):1224–1233. doi:10.1016/j.jse.2011.02.003
26. Constant CR, Murley AH (1987) A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res (214):160–164
27. Richards J, Inacio MC, Beckett M, Navarro RA, Singh A, Dillon MT, Sodl JF, Yian EH (2014) Patient and procedure-specific risk factors for deep infection after primary shoulder arthroplasty. Clin Orthop Relat Res 472(9):2809–2815. doi:10.1007/s11999-014-3696-5
28. Singh JA, Sperling JW, Schleck C, Harmsen WS, Cofield RH (2012) Periprosthetic infections after total shoulder arthroplasty: a 33-year perspective. J Shoulder Elbow Surg 21(11):1534–1541. doi:10.1016/j.jse.2012.01.006

29. Gorbaty JD, Lucas RM, Matsen FA, 3rd (2016) Detritic synovitis can mimic a Propionibacterium periprosthetic infection. Int Orthop 40(1):95–98. doi:10.1007/s00264-015-3032-z
30. Postacchini R, Carbone S, Canero G, Ripani M, Postacchini F (2015) Reverse shoulder prosthesis in patients with rheumatoid arthritis: a systematic review. Int Orthop. doi:10.1007/s00264-015-2916-2
31. Maier GS, Horas K, Seeger JB, Roth KE, Kurth AA, Maus U (2014) Is there an association between periprosthetic joint infection and low vitamin D levels? Int Orthop 38(7):1499–1504. doi:10.1007/s00264-014-2338-6
32. Shahi A, Parvizi J (2015) Prevention of Periprosthetic Joint Infection. Arch Bone Joint Surg 3(2):72–81