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REVIEW ARTICLES

Outcomes of revision surgery after periprosthetic shoulder infection: a systematic review

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Background: Periprosthetic shoulder infection (PSI) is one of the most challenging complications after shoulder arthroplasty. Different treatments have been proposed, but the best surgical procedure remains disputed in the current literature. This systematic review investigated the outcomes of revision surgery after PSI.

Methods: The PubMed and Scopus databases were used to search keywords in April 2018. Of 2157 titles, 34 studies were finally analyzed. Demographics, laboratory and microbiological data, types of implants, surgical techniques with complications and reoperations, eradication rates, and clinical and functional outcomes were reported.

Results: A total of 754 patients were identified. *Cutibacterium acnes* (*C. acnes*) was the most common microorganism found both in PSI (33%) and persistent infections (40%). Preoperatively, C-reactive protein was elevated in 70% of patients with PSI. Reverse shoulder arthroplasty had a lower prevalence of infection ($P < .001$). The eradication rate was 96% with 1 stage, 93% with permanent spacers, 86% with 2 stages, 85% with resection arthroplasty, and 65% with irrigation and débridement. One-stage revision was the best treatment, considering postoperative flexion and abduction, compared with resection arthroplasty, permanent spacers, and 2-stage revision. One-stage revision showed fewer postoperative complications than irrigation and débridement, resection arthroplasty, and 2-stage surgery. Two-stage surgery was the most common treatment, and the functional score demonstrated no differences between 2-stage and 1-stage procedures.

Conclusions: Our review suggests that a 1-stage procedure should be recommended to treat PSI. Two-stage revision could be reserved for select cases in which the bacterium involved is unknown.

Level of evidence: Level IV; Systematic Review

Keywords: Periprosthetic shoulder infection; shoulder revision surgery; one-stage; two-stage; total shoulder arthroplasty; reverse shoulder arthroplasty; *Cutibacterium acnes*; outcomes

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Shoulder arthroplasty has increased over the last decade,[30,54,63] and periprosthetic shoulder infection (PSI) is one of its most challenging and devastating complications. The incidence of PSI ranges from 1% to 4% for total

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shoulder arthroplasty (TSA) and from 2% to 19% for reverse shoulder arthroplasty (RSA), and can be as high as 15% in revision cases.[2,23,29]

The literature about PSI has been limited; thus, diagnostic and therapeutic algorithms have been adopted from the more extensive experience with total hip and knee arthroplasty, and Parvizi's criteria are commonly used to diagnose PSI.[4,39,64]

Clinical presentation is classified according to Sperling's criteria[50] as acute (<3 months), subacute (3 months to 1 year), and chronic (>1 year), and the most common PSI-causative organisms are *Cutibacterium acnes* and (*C. acnes*) Staphylococcus species, above all *S. aureus* and *S. epidermidis*; often, polymicrobial infections coexist.[45,50]

Different treatment approaches have been used, including conservative treatment with chronic suppressive antibiotic therapy and surgical treatment, such as arthroscopic or open irrigation and débridement with or without component retention, permanent articulating antibiotic spacers, resection arthroplasty with or without arthrodesis, 1- and 2-stage revision arthroplasty, arthrodesis, and amputation.[10,15,44,47-50,53,55] Although there are several options, the management of PSI has not been standardized, and the current literature remains controversial. There have been no randomized, controlled trials or prospective, controlled studies on the surgical treatment of PSI. Which procedure is most effective at eradicating the infection while providing better functional outcomes and fewer complications is still under debate. The aim of this systematic review was to investigate the outcomes of revision surgery after PSI.

Materials and methods

A systematic review was performed using 2 common databases, PubMed and Scopus, in April 2018. The search terms used were "shoulder arthroplasty infection outcome," "shoulder arthroplasty infection results," "shoulder replacement infection outcome," and "shoulder replacement infection results." In PubMed and Scopus, 250 and 610 titles were found, respectively, for "shoulder arthroplasty infection outcome," 387 and 713 for "shoulder arthroplasty infection results," 201 and 442 for "shoulder replacement infection outcome," and 294 and 524 for "shoulder replacement infection results." Following the PRISMA statement guidelines,[31] 2 authors independently reviewed the titles, removed duplicates, and included in the study those addressing PSI or shoulder arthroplasty revision surgery; review articles were excluded but considered to assist in writing the discussion and conclusion.

Thus, 140 studies were identified, and the related abstracts were reviewed by the same 2 authors using the following exclusion criteria: case report or case series of <5 patients; a minimum mean follow-up of <12 months; studies not related to PSI; and reviews not identified by the title. On the basis of these criteria, 77 studies were available for the current review. These studies were further evaluated by the same 2 authors for a full text review, including only papers written in English and excluding editorials, technique articles, nonoperative management, and articles without outcomes or results. Finally, the reference list of each selected article was checked to identify additional studies missed in the first electronic search. After this last check, 34 articles were available for final analysis (Figure 1).[1,2,5,8-12,15,16,18-22,25-28,33,34,38,42-44,46,50-53,58,59,61,62]

Patients' demographics (sex, age, length of follow-up, and follow-up rate) and acuity of presentation were analyzed. Because of the heterogeneity of infection acuity reported among the studies, acute and subacute infections were aggregated to improve the interpretation of the data. Therefore, PSIs were divided into 2 groups based on less or more than 12 months having passed after arthroplasty.

Pre- and postoperative laboratory and microbiology data were evaluated. In detail, the white blood cell (WBC) count, erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) levels were analyzed. Because different reference ranges were present, laboratory data were divided into a binary group to identify normal or abnormal values. An analysis of the laboratory data for each patient was included. In addition, the whole study population was considered abnormal for the laboratory parameters if at least two-thirds of the patients reported out of range values.

When not specified, standard deviations were calculated from the ranges (max range-min range/4) to allow for statistical comparisons. Frequency-weighted means and grouped standard deviations were used to compare subgroups whenever available. Treatments for PSI were divided into 5 groups: irrigation and débridement; resection arthroplasty; permanent spacers as definitive treatment; and 1- and 2-stage revision. For an additional analysis, irrigation and débridement, resection arthroplasty, and permanent spacers were aggregated as nonexchange procedures, and 1- and 2-stage procedures were aggregated as exchange procedures. Primary and revision implants (hemi-, total, or reverse shoulder arthroplasty) were evaluated, and outcome scores were reported as the mean, range, and standard deviation. Pre- and postoperative microbiology data were reported, and the eradication rate was calculated. The following outcome scores were evaluated: Constant-Murley score (CMS), Simple Shoulder Test (SST), and American Shoulder and Elbow Surgeons Shoulder score. Range of motion (ROM) and pain, evaluated using a standardized visual analog scale, were also reported. Pre- and postoperative degrees of active flexion, abduction, and external rotation were recorded. Because of the inconsistent method of reporting internal rotation throughout the studies, this movement was not analyzed in the current review. Intra- and postoperative problems and complications, reoperation, and revision were evaluated according to Zumstein et al.[65] A problem was defined as an intraoperative or postoperative event that was unlikely to affect the patient's final outcome, including radiographic scapular notching, hematomas, heterotopic ossification, algodystrophy, phlebitis, intraoperative dislocations, intraoperative cement extravasation, or radiographic lucent lines of the glenoid. A complication was defined as any intraoperative or postoperative event that was likely to have a negative influence on the patient's final outcome, including fractures, infections, dislocations, nerve palsies, aseptic loosening of humeral or glenoid components, modular stem or polyethylene disassociations, or glenoid screw problems. Reoperations were defined as interventions requiring any return to the operating room for any reason relating to the shoulder, without altering or replacing any of the components. Revisions were defined as surgeries with total or partial exchange

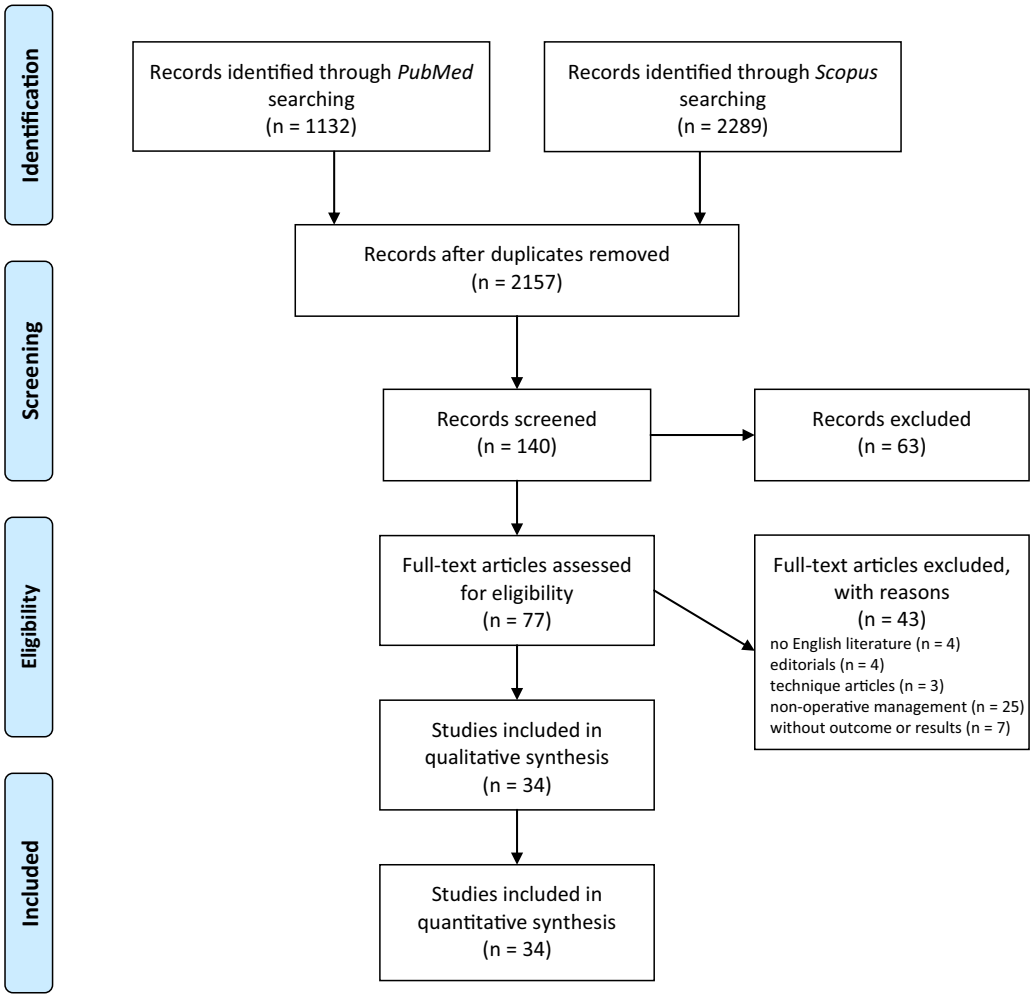

Figure 1 Literature review and PRISMA flow diagram. From Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;6:e1000097. For more information, visit www.prisma-statement.org

or removal of the components. Liner exchanges and additions of humeral spacers were considered revisions.

IBM SPSS Statistics software (version 21.0.0.1; IBM Corp., Armonk, NY, USA) and GraphPad Prism software (GraphPad Software, Inc., San Diego, CA, USA) were used for the database construction and the statistical analysis; all of the data were collected, measured, and reported with 1-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 $< .05$ was considered significant.

Results

Demographics

This systematic review included 34 studies published between 2001 and April 2018 with 863 patients. A total of 754 patients (87%) were available at follow-up, and there was a statistically significant difference ($P = .003$) between the number of male (57%) and female patients (43%). The number of PSIs surgically treated was 721. The frequency-weighted mean age was 65 ± 12 years, the frequency-weighted follow-up was 41 ± 30 months, and the frequency-weighted follow-up rate was 90% (Table I). Data on infection acuity were available for 382 patients.[1,2,5,8-11,15,18,19,25-28,33,38,50,53,58,61] The acuity of presentation was <12 months in 37% of patients and >12 in 62%.

The type of infected implant was evaluated for 460 PSIs,[1,2,5,8,9,11,12,15,18,21,25,28,33,38,43,44,50,51,53,58,59,61,62] and hemiarthroplasty (HA), total shoulder arthroplasty (TSA), reverse shoulder arthroplasty (RSA), and other implants represented 39%, 38%, 22%, and 2%, respectively. A lower prevalence of infection was observed in RSA, compared with HA and TSA ($P < .001$ for both).

The numbers of patients with elevated laboratory parameters in the different studies are shown in Table II. The studies with at least two-thirds of the patients with preoperative laboratory values within reference ranges were 84% for WBC, 33% for ESR, and 7% for CRP.

Table I Demographics of included studies

Author	Journal	Year of publication	Scientific level	Patient demographics												
				Initial patients	Sex		Available for examination		Age (yr)			FU (mo)			FU rate (%)
					M	F	Patients	PSI surgically treated	Mean	Range	SD	Mean	Range	SD	
Achermann et al[1]	*Infection*	2013	4	16	5	11	16	14	67	53-86	8.3*	>12	na	na	100
Assenmacher et al[2]	*J Shoulder Elbow Surg*	2017	4	39	25	9	34	35	65	na	10.5	49.2	24-214.8	47.7*	87.2
Beekman et al[5]	*J Bone Joint Surg Br*	2010	4	11	9	2	11	11	62	39-79	10*	24	12-36	6*	100
Braman et al[8]	*J Shoulder Elbow Surg*	2006	4	20	4	3	7	7	69	61-78	4.3*	20	12-41	7.3*	35.0
Buchalter et al[9]	*J Shoulder Elbow Surg*	2017	4	19	14	5	19	19	63	47-78	9	63	25-184	39.8*	100
Coste et al[10]	*J Bone Joint Surg Br*	2004	4	49	23	19	42	34	64	36-87	12.8*	32	12-96	21*	85.7
Cuff et al[11]	*J Bone Jt Surg Br*	2008	4	21	10	11	21	17	67	43-83	10*	43	25-66	10.3*	100
Dennison et al[12]	*J Shoulder Elbow Surg*	2017	4	9	4	5	9	10	69	33-85	13*	49.2	7-153.6	36.7*	100
Ghijselings et al[15]	*Acta Orthop Belg*	2013	4	23	9	8	17	17	60.5	34-74	10*	56.4	12-108	24*	73.9
Grosso et al[16]	*J Shoulder Elbow Surg*	2012	4	17	13	4	17	17	65.5	60.9-72	2.8*	35.8	22-84	15.5*	100
Hsu et al[18]	*J Bone Jt Surg*	2016	3	55	35	20	55	55	65.3	na	7.8	47.8	na	11.8*	100
Ince et al[19]	*J Bone Jt Surg*	2005	4	16	10	6	9	9	68	45-90	11.3*	69.6	13-159	36.5*	56.3
Jacquot et al[20]	*J Shoulder Elbow Surg*	2015	4	35	19	13	32	32	71	55-83	7*	36	12-137	31.3*	91.4
Jawa et al[21]	*J Bone Jt Surg Am*	2011	4	30	20	8	28	28	63	31-82	12.8*	27.6	12-69	14.3*	93.3
Jerosch et al[22]	*Arch Orthop Trauma Surg*	2003	3	12	na	na	12	12	71	56-82	6.5*	>12	na	6*	100
Klatte et al[25]	*Bone Jt J*	2013	4	35	19	16	35	35	66	41-90	12.3*	56.4	13.2-159	36.5*	100
Lee et al[26]	*Int Orthop*	2018	4	14	5	7	12	12	69.5	48-84	9*	40.9	36-52	4*	85.7
Levy et al[27]	*Orthopedics*	2015	4	14	6	3	9	9	72.3	62-80	4.5*	25	12-48	9*	64.3
Mahure et al[28]	*Orthopedics*	2016	4	9	6	3	9	9	73	60-87	9	48	26-132	35.1	100
Ortmaier et al[33]	*Eur J Orthop Surg Traumatol*	2014	4	21	12	8	20	20	65.2	53-82	7.3*	73.7	24-115	22.8*	95.0
Padegimas et al[34]	*Clin Orthop Surg*	2017	4	37	16	21	37	37	67.6	na	9	45.1	18-62.4	11*	100
Pellegrini et al[38]	*Arch Orthop Trauma Surg*	2018	4	23	10	9	19	19	70.2	67-80	10.2	96	24-120	24*	82.6
Rispoli et al[42]	*J Bone Joint Surg Br*	2007	4	34	8	10	18	13	37	51-79	7*	99.6	30-199.2	42.3*	52.9
Romanò et al[43]	*Int Orthop*	2012	4	53	16	28	44	44	63	28-80	10.2	41.1	24-98	17.9	83
Sabesan et al[44]	*Clin Orthop*	2011	4	27	10	7	17	17	67.6	na	10.3	46.2	22-80	14.5*	63
Seitz et al[46]	*J Arthroplasty*	2002	4	5	na	na	5	5	62	28-76	12*	57.6	36-96	15*	100
Sperling et al[50]	*Clin Orthop*	2001	4	33	14	17	31	32	54	24-75	12.8*	>24	na	na	93.9
Stine et al[51]	*J Shoulder Elbow Surg*	2010	4	30	19	11	26	17	61	41-86	11.3*	>24	na	na	86.7
Stone et al[52]	*J Shoulder Elbow Surg*	2017	3	89	52	37	89	79	66	27-92	16.3*	45	12-105	23.3*	100
Strickland et al[54]	*J Bone Joint Surg Br*	2008	4	17	10	7	17	19	62	41-75	8.5*	35	24-80	14*	100
Verhelst et al[58]	*J Shoulder Elbow Surg*	2011	3	21	na	na	9	9	61.2	38.5-72.8	8.6*	46.4	17-101	21*	na
Weber et al[59]	*Int Orthop*	2011	4	10	4	6	10	10	63.1	33-89.1	14*	48	14.4-120	26.4*	100
Zavala et al[61]	*J Shoulder Elbow Surg*	2012	4	8	3	4	7	7	na	na	na	43.5	na	na	87.5
Zhang et al[62]	*J Shoulder Elbow Surg*	2015	4	11	9	2	11	11	69	52-88	9*	24	12-36	6*	100
		2001-2018		863	419	320	754	721	64.5	24-92	12.1	40.6	12-214.8	29.5	90.3

FU, follow-up; *PSI,* periprosthetic shoulder infection; *SD,* standard deviation; *na,* not applicable.

* Calculated from the range (range/4).

Table II Preoperative laboratory parameters

Author	PSI surgically treated	WBC			ESR			CRP		
		Available Values	Normal	Elevated	Available Values	Normal	Elevated	Available Values	Normal	Elevated
Assenmacher et al[2]	35	33	32	1	31	12	19	30	10	20
Beekman et al[5]	11	11	11	0	11	4	7	11	3	8
Buchalter et al[9]	19	16	15	1	11	5	6	13	5	8
Cuff et al[11]	17	16	7	9	10	3	7	9	3	6
Dennison et al[12]	10	na	na	na	10	2	8	7	4	3
Ghijselings et al[15]	17	na	na	na	na	na	na	17	1	16
Ince et al[19]	9	16	15	1	15	2	13	15	1	14
Jawa et al[21]	28	28	27	1	23	7	16	19	4	15
Jerosch et al[22]	12	na	na	na	na	na	na	12	0	12
Klatte et al[25]	35	14	11	3	na	na	na	34	6	28
Lee et al[26]	12	na	na	na	12	0	12	12	0	12
Levy et al[27]	9	11	10	1	13	7	6	13	5	8
Mahure et al[28]	9	5	4	1	6	1	5	6	1	5
Ortmaier et al[33]	20	20	15	5	na	na	na	20	7	13
Sabesan et al[44]	17	14	14	0	13	2	11	13	2	11
Seitz et al[46]	5	5	0	5	5	0	5	na	na	na
Sperling et al[50]	32	29	27	2	24	10	14	na	na	na
Stone et al[52]	79	69	66	3	69	36	33	68	32	36
Strickland et al[54]	19	19	19	0	17	9	8	16	8	8
Verhelst et al[58]	9	na	na	na	9	8	1	9	6	3
Weber et al[59]	10	10	9	1	na	na	na	9	1	8
No. total	414	316	282	34	279	108	171	333	99	234
Percent		100	89	11	100	39	61	100	30	70

PSI, periprosthetic shoulder infection; *WBC,* white blood cells; *ESR,* erythrocyte sedimentation rate; *CRP,* C-reactive protein; *na,* not applicable.

Twenty of 34 studies determined the causative germ preoperatively. Data for 703 PSI perioperative cultured pathogens were reported,[1,2,5,8-12,15,16,18,19,20-22,25,26,28,33,34,38,44,50-53,58,59,61,62] and the most common organisms were *C. acnes* (33%), coagulase-negative *Staphylococcus* (CNS) (21%), methicillin-sensitive *Staphylococcus aureus* (MSSA) (13%), and *S. epidermidis* (10%) (Table III). Cultures not specified amounted to 6% of the total.

Surgical technique

Because some patients underwent multiple revision procedures, the number of shoulders subjected to revision surgery was 721, but the total number of treatments was 734. There was a similar distribution of treatments performed for PSI in the resection arthroplasty, permanent spacer, and irrigation and débridement groups (12%, 11%, and 11%, respectively); 1- and 2-stage revisions were the most common procedures (26% and 40%, respectively).

The rate of infections occurring earlier than 12 months after the primary surgery was 80% with irrigation and débridement, 34% with resection arthroplasty, 29% with permanent spacers, 28% with 1-stage revision, and 40% with 2-stage revision.

The type of implant used for the revision surgery was available for 417 patients, [2,5,9,11,15,16,18,19,21,22,25,26,33,34,43,44,50,51,53,59,62] and in detail, 49% were RSA, 35% were HA, 14% were TSA, and 2% were other implants. The number of RSAs used as revision implants was significantly higher than the numbers of HAs and TSAs ($P < .001$ for both).

In the group treated with 1-stage procedures, HAs (52%) were the infected implants most represented, and there were a significantly higher number of such implants in this group ($P = .023$), compared with the 2-stage group. In the 2-stage group, TSAs (56%) were the most common infected implant, and a greater number of this type of implant ($P < .001$) was observed, compared with the 1-stage group (Table IV).

Regarding revision implants, a greater number of HAs compared with TSAs ($P = .001$) and RSAs ($P = .003$) were used in 1-stage revision surgeries. A greater number of RSAs compared with the HAs and TSAs ($P < .001$ for all) were used in the 2-stage procedures (Table IV).

Clinical and functional outcomes

The postoperative clinical and functional outcome data are shown in Table V. The overall postoperative CMS of the

Table III Causative organism in PSI and persistent PSI

Organism	PSI		Persistent PSI	
	No.	Prevalence %	No.	Prevalence %
C. acnes	226	32.5	12	40
CNS	144	20.7	3	10
MSSA	89	12.8	4	13.3
S. epidermidis	68	9.8	3	10
Cultures not otherwise specified	40	5.7	na	na
MRSA	35	5	2	6.7
Others	35	5	4	13.3
Polymicrobial not otherwise specified	30	4.3	na	na
P. aeruginosa	15	2.2	na	na
Corynebacterium spp	15	2.2	1	3.3
E. faecalis	10	1.4	na	na
Enterococcus spp	10	1.4	1	3.3
Peptostreptococcus spp	8	1.2	na	na
Serratia marcenscens	6	0.9	na	na
E. coli	5	0.7	na	na

PSI, periprosthetic shoulder infection; *No.,* pooled sample size across manuscripts; *CNS,* coagulase-negative Staphylococcus; *MSSA,* methicillin-sensitive *Staphylococcus aureus*; *MRSA,* methicillin-resistant *Staphylococcus aureus*; *Others*, organisms reported in less than 5 cases; *na,* not applicable.
Data pooled from the following references: [1,2,5,8-12,14,15,17-21,24,25,27,32,33,37,43,49-52,57,58,60,61].

Table IV Types of implants

	One-stage		Two-stage	
	Preop (%)	Postop (%)	Preop (%)	Postop (%)
HA	51.5	44.9	34.7	27.5
TSA	23.8	23.7	56.4	14.6
RSA	16.8	25.4	8.9	57.9
Other	7.9	6	na	na

Preop, preoperative; *Postop,* postoperative; *HA,* hemiarthroplasty; *TSA,* total shoulder arthroplasty; *RSA,* reverse shoulder arthroplasty; *na,* not applicable.
Data pooled from the following references: [2,5,9,11,14,15,17,18,20,21,24,25,32,33,42,43,49,50,52,58,61].

nonexchange and exchange procedures was 35 ± 14 and 47 ± 17, respectively ($P < .001$). Postoperative CMS[5,10,15,19,20,25,26,33,38,43,58,59] was significantly higher in patients who underwent irrigation and débridement, compared with resection arthroplasty and permanent spacers ($P < .001$ and $P = .009$, respectively). A higher postoperative CMS was also observed in patients treated with a 1-stage procedure, compared with irrigation and débridement, resection arthroplasty, and permanent spacers ($P = .042$, $P < .001$, and $P < .001$, respectively). Two-stage revision showed better postoperative CMS compared with resection arthroplasty and permanent spacers ($P < .001$ and $P < .001$, respectively). There were no significant postoperative CMS differences between the 1- and 2-stage procedures ($P = .151$).

Higher postoperative SST scores[15,18,27,33,42,51,52] were noted in irrigation and débridement, compared with resection arthroplasty ($P = .001$). One-stage revision showed higher postoperative SST scores than resection arthroplasty and permanent spacer ($P < .001$ and $P = .031$, respectively). Two-stage revision showed higher postoperative SST scores compared with resection arthroplasty ($P < .001$). No differences were noted between the postoperative SST scores after 1- and 2-stage procedures ($P = .127$).

Higher postoperative American Shoulder and Elbow Surgeons Shoulder scores[9,26-28,42,52,61,62] were observed after permanent spacers and the 2-stage procedure, compared with resection arthroplasty ($P = .004$ and $P < .001$, respectively).

ROM was evaluated by 22 studies,[2,8,9,12,16,21,26-28,33,34,38,42-44,50-53,59,61,62] and resection arthroplasty and permanent spacers showed lower postoperative degrees of flexion and abduction compared with irrigation and

Table V Postoperative clinical and functional outcomes

Procedure	CMS		SST score		ASES		Flexion (°)		Abduction (°)		External rotation (°)		VAS	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
ID	42.8	13.7	5.3	2.3	56.5	na	116	30	100	0	33	13	3.3	2.3
RA	28.8	12.6	2.9	2.6	35.4	16.3	50	38	53	37	25	28	3.7	2
SPC	33.8	17	4.4	2.7	61.4	21.4	73	32	57	21	12	30	2.3	2.5
One-stage	49.7	19.4	6.1	3.5	60	na	116	31	104	0	32	15	3.4	2.7
Two-stage	45.3	15.7	5.5	1.25	66.9	13.1	105	39	87	28	31	19	2.9	1.7

CMS, Constant-Murley score; *SST,* Simple Shoulder Test; *ASES,* American Shoulder and Elbow Surgeons Shoulder score; *VAS,* visual analog scale; *ID,* irrigation and débridement; *RA,* resection arthroplasty; *SPC,* spacer; *SD,* standard deviation; *na,* not applicable.

débridement and 1-stage and 2-stage revisions (all $P <$ .001). Similarly, permanent spacers showed lower postoperative external rotation than irrigation and débridement, and 1-stage and 2-stage revisions (all $P <$ .001). Irrigation and débridement and 1-stage revision showed higher abduction values than the 2-stage procedure (all $P <$ .001), but 1-stage revision had higher values than irrigation and débridement ($P <$ .001). Higher postoperative flexion and lower degrees of external rotation were noted in patients who underwent permanent spacers, compared with resection arthroplasty ($P =$ .01 and $P =$ .003, respectively). No statistically significant differences were noted for the postoperative visual analog scale scores among the surgical procedures.

Postoperative laboratory examinations and microbiology

Only 7 studies (103 cases) reported the values from blood examinations after treatment.[12,15,22,26,51,53,58] The percentages of patients showing WBC, ESR, and CRP within normal ranges were 100%, 91%, and 95%, respectively. The studies with at least two-thirds of the patients showing values within reference ranges were 100% for all of the laboratory parameters in 2-stage revision; 100% of ESR and CRP were within the reference ranges with irrigation and débridement, resection arthroplasty, and permanent spacers. No data were available after 1-stage revisions.

The overall eradication rates of nonexchange and exchange procedures were 82% and 90%, respectively ($P =$ .001). The eradication rate was 96% with 1 stage, 93% with permanent spacers, 86% with 2 stages, 85% with resection arthroplasty, and 66% with irrigation and débridement. One-stage revision showed a significantly higher eradication rate than all procedures but permanent spacers ($P <$ .001 for irrigation and débridement; $P =$ .003 for resection arthroplasty; $P <$ .001 for 2-stage). In contrast, irrigation and débridement showed a significantly lower eradication rate compared with all other procedures ($P <$ .001 for permanent spacers, 1-stage, and 2-stage; $P =$ .007 for resection arthroplasty).

The organisms responsible for persistent infections (99) were *C. acnes* (40%), *MSSA* (14%), *CNS* (10%), and *S. epidermidis* (10%) (Table III).

Problems and complications

Postoperative complications were observed in 38% (31 of 81 cases) of irrigation and débridement, 31% (27 of 87 cases) of resection arthroplasty, 17% (14 of 84 cases) of permanent spacers, 11% (21 of 190 cases) of 1-stage, and 25% (74 of 292 cases) of 2-stage. For all the procedures, most of the complications consisted of persistent infections as reported above; the remaining complications more frequently observed were as follows: 7% instability and 3% neurologic complications for irrigation and débridement; 37% fractures and 7% neurologic complications for resection arthroplasty; 36% fractures, 7% loosening, and 7% instability/dislocation for permanent spacers; 24% instability/dislocation, 14% neurologic complications, and 14% loosening for 1-stage; 27% instability/dislocation and 11% fracture for 2-stage. No differences in postoperative problems were found between 1- (8%) and 2-stage (5%) revisions. In 1-stage revision, lower postoperative complications were noted compared with irrigation and débridement, resection arthroplasty, and 2-stage ($P <$ .001 for all). Similarly, lower postoperative complications were noted with 2-stage revision compared with irrigation and débridement ($P =$ .026). Permanent spacers showed fewer postoperative complications than irrigation and débridement and resection arthroplasty ($P =$ .003 and $P =$ .032, respectively).

Reoperations and revisions

Reoperations occurred in 16% of patients after irrigation and débridement, 4% after resection arthroplasty, 2% after 1-stage, and 1% after 2-stage procedures. Revisions occurred in 25% of patients after irrigation and débridement, 10% after permanent spacers, 6% after 1-stage, and 15% after 2-stage procedures. Irrigation and débridement had the greatest number of reoperations ($P =$

.007 compared with resection arthroplasty; $P < .001$ compared with 1-stage and 2-stage; no available data for permanent spacers) and revisions ($P < .001$ compared with 1-stage and $P = .009$ compared with permanent spacers and $P = .044$ compared with 2-stage; no available data for resection arthroplasty), compared with other procedures.

Discussion

No prospective, randomized, controlled studies have been performed comparing the surgical techniques for PSI; thus, the current study is a systematic review of Level III and IV studies, providing an overview of the available literature regarding the outcomes after surgical treatment of PSI.

In the current review, *C. acnes* was the most common causative microorganism of PSI, and preoperatively, CRP was elevated in 70% of PSIs. Reverse shoulder arthroplasty had a lower prevalence of infection. Two-stage was the most common treatment; however, 1-stage revision achieved higher postoperative flexion and abduction than resection arthroplasty; permanent spacers and 2-stage revision showed lower postoperative complications than irrigation and débridement, resection arthroplasty, and 2-stage surgery. A significantly higher eradication rate was found for the exchange procedures compared with the nonexchange procedures.

As far as we know, only 2 systematic reviews have been published on outcomes after surgical treatments of PSI.[29,32] The current review focused exclusively on the surgical treatment of PSI, in contrast to Nelson et al,[32] who also included data from patients treated with antibiotic-alone therapy. The number of clinical and functional scores and the total articles included in the current study are considerably greater than those evaluated in the paper by Marcheggiani Muccioli et al,[29] who limited their analysis to the CMS of patients and excluded series with follow-ups shorter than 24 months. Moreover, none of the previously published reviews evaluated postoperative laboratory data, microbiology of persistent PSI after treatment, the types of primary implants and those used for revision surgery, and the problems and complications of reoperation or revision procedures.

Most of the patients included in this review were male, in agreement with previous studies reporting an increased risk for PSI in men.[10,57,61] Patel et al[37] suggested that the shoulder skin region has a higher bacterial load of *C. acnes* than other body regions, which could be sex related.

ESR and CRP are well-known biomarkers of systemic responses to inflammation,[14] and the assessment of patients' serum ESR and CRP levels has been recommended as the first line of diagnostic evaluation in patients with suspected periprosthetic joint infection (PJI).[3,35,36] However, these laboratory data, which are used extensively in the diagnosis of hip and knee PJI, have found inconsistent utility in the diagnosis of PSI. Piper et al,[39] who examined infected hips, knees, and shoulders, reported a negative predictive value for ESR of 77% in the shoulder, whereas it was higher than 90% in the hip and knee. In the setting of shoulder arthroplasty, the sensitivity of CRP has varied in the studies: Dennison et al[12] reported a sensitivity for CRP of 30%, Dodson et al[13] reported a sensitivity for CRP of 91%, and Grosso et al[16] reported a sensitivity for CRP of 46%. Nelson et al[32] found CRP to be elevated more than 50% of the time in PSI; however, the authors also included in their review patients treated with antibiotic therapy alone. We found that 70% of patients with PSI had abnormal CRP values preoperatively, and elevated levels of CRP, rather than ESR, are more commonly observed. Based on these data, ESR and CRP lack adequate sensitivity to exclude infection in PSI.

The differences in the predictive values of laboratory biomarkers to diagnose persistent infection between PJI of the hip or knee and PSI can be related to the different types of causative bacteria. Indeed, a high prevalence of *C. acnes* is commonly reported in PSI, whereas this microorganism is seldom responsible for hip or knee PJI. Notably, *C. acnes* has low virulence; thus, a limited, local inflammatory response can be expected with serological markers frequently within normal ranges. Interestingly, the prevalence of *C. acnes* was 32% in the current series.

The prevalence of causative germs might also explain the data reported for the acuity of infection. Indeed, low virulence organisms lead to PSI manifesting between 3 months and 24 months after surgery,[40] and in the current series, 62% of PSI cases occurred after 12 months.

C. acnes was also the most common organism responsible for persistent infections, and this observation is in agreement with 2 previous studies.[17,21] Interestingly, the isolation of *C. acnes* in microbial culture specimens has been reported to be a specific risk factor for failure of treatment for PSI. Topolski et al[56] and Kelly and Hobgood[24] reported that 50% and 100% of recurrences, respectively, were caused by *C. acnes*.

In the current study, HA and TSA were the implants most commonly revised, whereas RSA was the least frequent type of infected implant. A recent multicentric prognostic study found that patients who underwent primary RSA had a 6-fold higher risk of infection than patients who underwent primary TSA.[41] These apparently conflicting data could be explained by the recent increase in the number of RSAs performed worldwide.[60] In this light, most of the studies evaluated in this review were published more than 5 years ago and more frequently reported on PSI after TSA or HA.

The management of PSI is individually based on the time of appearance of the infection, the nature of the bacteria and their antibiotic sensitivities, the patient's age, the specific comorbidities, the local bony situation, and the stability of the implant. As expected, in the current review, irrigation and débridement, among the other techniques, was more commonly used when PSI occurred within the

first year. In contrast, 2-stage revision was the most common treatment for chronic PSI. Moreover, when TSA was revised through a 2-stage procedure, RSA was the prevalent revision implant. For reimplantation, RSA has gained ground in recent years as the implant of choice because it allows for greater débridement in the first stage with less concern for soft-tissue preservation. In addition, RSA offers the possibility of addressing glenoid bone defects with or without bone grafts.[6]

The current review demonstrated that open or arthroscopic irrigation and débridement is commonly used to manage PSI in acute presentation because it represents a minimally invasive surgery with postoperative outcomes and ROM comparable with other nonexchange procedures; however, the high complication rate and the low eradication rate represent important limitations of this technique.

Resection arthroplasty showed an 85% eradication rate. However, in contrast to the hip or knee joints, the shoulder does not sustain an axial load, and poor ROM and outcome scores were noted in this review; moreover, high postoperative complications have been reported. Therefore, this procedure can be reserved for patients without infection control,[58] or to avoid longer and more invasive surgeries, as long as preoperative counseling about permanent postoperative limitations has been provided.[8]

As already reported,[34] permanent spacers are a useful procedure considering the high eradication rate and the low risk of complications; however, lower functional outcomes compared with exchange procedures indicate that this surgical option remains a viable procedure, either as a bridge to reimplantation or as a definitive treatment for patients with many comorbidities or low functional requests.

The option of a single definitive procedure for infection eradication is attractive, especially for frail or low-demand patients. We noted that the 1-stage procedure was more commonly reserved to treat infected HA. HA was also the more common implant used for 1-stage revision, related to the shorter operative time and elimination of potential component loosening, polyethylene wear problems, and bone-sparing.[7] It can also be hypothesized that in cases of persistent infection, the revision of an HA is considered a less challenging procedure than an RSA or TSA revision.

One-stage revision was found to have the best eradication rate in PSI treatment, whereas irrigation and débridement showed the worse eradication rate, and the 1-stage revision data concurred with a previous review.[29] Only the eradication rate with permanent spacers was not significantly different from the 1-stage procedure. However, 1-stage revision was the best treatment in terms of postoperative flexion and abduction, compared with resection arthroplasty, permanent spacers, and 2-stage revision. The highest postoperative CMS and SST scores were noted after 1-stage revision, although we failed to find statistically significant differences with the 2-stage procedure. In contrast to previous articles that reported a higher risk of complications for 1-stage revision compared with 2-stage revision,[2,19] we observed fewer postoperative complications if the 1-stage procedures were compared with irrigation and débridement, resection arthroplasty, and 2-stage procedures. We could explain this discrepancy by assuming that the definition of complications greatly differs among the studies. Rangan et al[40] suggested choosing 1-stage revision when the causative germ has low virulence or is easily treatable or if multiple procedures are contraindicated because of risks to the patient.

We next demonstrated that 2-stage revision is the most common procedure for managing PSI. Indeed, 2-stage revision is considered the most reproducible way to deliver the eradication of infection.[44] This technique is more commonly used to revise TSA, and the implant chosen for revision is RSA. As previously reported,[29] this choice could be driven by the need for extensive release in the case of soft tissue retractions, which is a common problem after 2-stage procedures. Functional outcomes after 2-stage procedures did not differ compared with 1-stage procedures; however, lower eradication rates and ROM with a higher complication rate could orient surgeons toward choosing a 2-stage procedure when the bacterium involved is unknown. The patient should be informed that more surgical procedures could be necessary, each with high perioperative risk and longer hospitalization and healing time.[9]

As is typical of any systematic review, the inherent weakness of each individual study translates into limitations of this review. The methodologies of the articles reviewed did not provide controls for bias or confounding factors, because the articles were mainly of a descriptive nature. Weaknesses inherent to the individual studies are not improved by aggregating them. Because of the heterogeneity of the studies evaluated, it was not possible to determine any variable influencing the infection rate for the whole population. A further limitation of this review is the use of different methods of outcome evaluation among the studies reviewed. Moreover, it was not possible to determine whether there were any differences in the outcomes among patients treated with HA, TSA, or RSA because most of the included studies reported the mean values of different procedures without differentiating different implants.

Conclusion

C. acnes is the bacterium most often responsible for PSI and persistent infection after revision, and CRP represents the laboratory biomarker most commonly elevated in PSI. HA and TSA are the most commonly infected implants. A 2-stage procedure is the technique most frequently used to manage PSI, and RSA is the implant usually chosen for revision surgery.

Irrigation and débridement is the preferred technique for acute and subacute infections; however, it is characterized by a lower eradication rate. Among the non-exchange procedures, spacer and resection arthroplasty show a high eradication rate and a low risk of complications; however, lower functional outcomes compared with exchange procedures limit the indications for these techniques. The 1-stage procedure is the best treatment in terms of eradication rate, postoperative ROM, and postoperative complications, but no statistically significant differences were noted between the 1- and 2-stage surgeries. Therefore, 2-stage revision could be reserved for when the bacterium involved is unknown.

Disclaimer

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