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The modern reverse shoulder arthroplasty and an updated systematic review for each complication: part I

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A R T I C L E I N F O

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Level of evidence: Level IV; Systematic Review

Background: Globally, reverse shoulder arthroplasty (RSA) has moved away from the Grammont design to modern prosthesis designs. The purpose of this 2-part study was to systematically review each of the most common complications of RSA, limiting each search to publications in 2010 or later. In this part (part I), we examined (1) scapular notching (SN), (2) periprosthetic infection (PJI), (3) mechanical failure (glenoid or humeral component), and (4) neurologic injury (NI).

Methods: Four separate PubMed database searches were performed following Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines. Overall, 113 studies on SN, 62 on PJI, 34 on mechanical failure, and 48 on NI were included in our reviews. Univariate analysis was performed with the χ^2 or Fisher exact test.

Results: The Grammont design had a higher SN rate vs. all other designs combined (42.5% vs. 12.3%, $P < .001$). The onlay humeral design had a lower rate than the lateralized glenoid design (10.5% vs. 14.8%, $P < .001$). The PJI rate was 2.4% for primary RSA and 2.6% for revision RSA. The incidence of glenoid and humeral component loosening was 2.3% and 1.4%, respectively. The Grammont design had an increased NI rate vs. all other designs combined (0.9% vs. 0.1%, $P = .04$).

Conclusions: Focused systematic reviews of the recent literature with a large volume of RSAs demonstrate that with the use of non-Grammont modern prosthesis designs, complications including SN, PJI, glenoid component loosening, and NI are significantly reduced compared with previous studies. As the indications for RSA continue to expand, it is imperative to accurately track the rates and types of complications to justify its cost and increased indications.

Although initially indicated for patients with rotator cuff arthropathy,[14,70] reverse shoulder arthroplasty (RSA) has been used to treat various other pathologies including irreparable rotator cuff tears without arthropathy,[51] inflammatory arthritis,[83] displaced proximal humeral fractures (PHFs) in elderly patients,[111] and fracture sequelae.[164] Recently, indications have expanded to include osteoarthritis (OA) with posterior subluxation and a biconcave glenoid[136] or other patterns of advanced symmetrical glenoid wear or dysplasia, as well as tumor resection, post-infectious sequelae,[44] and chronic dislocations. Furthermore, RSA has been shown to have favorable outcomes when used to revise failed primary shoulder arthroplasty and failed osteosynthesis after PHF.[27] Thus, RSA is frequently used to treat difficult clinical diagnoses, many of which are salvage conditions, and it is not surprising to see a relatively high reported complication rate.[13]

As the volume of RSA increases,[49] with continued increases expected over the next 10 years,[156] precise knowledge of the probability and implications of the various complications is imperative for judicious use of RSA.[57] The complications have been well described; the studies in the literature, however, are heterogeneous (eg, different indications, different prostheses, and

Institutional review board approval was not required for this systematic review.

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different populations) and definitions vary between authors.[34,223] The reported complication rate is variable among reports and seems to be influenced substantially by the mix of primary and revision procedures included in each study,[178] with 1 study noting the highest rate with RSAs used to revise failed primary RSAs.[27] Other major influences may include prosthesis design and surgeon experience,[187,208] with some authors advocating that primary shoulder arthroplasty is performed more efficiently by higher-volume surgeons.[187] Patient factors including body mass index,[6] diabetes,[123] Parkinson disease,[30] and preoperative American Society of Anesthesiologists score[91] have all been linked to increased complications and/or unfavorable outcomes.

The majority of the published studies on RSA have historically reported on a Grammont-style RSA (glenosphere with a medialized center of rotation [medialized glenoid (MG)] along with an inlay humeral component that medializes the humerus [medialized humerus (MH)]). Lessons learned using this style of prosthesis have led to the introduction of new designs with multiple options for glenosphere lateral offset and eccentricity, different neck-shaft angulations, and humerus-based lateralization (lateralized humerus [LH]). These design modifications translate into different biomechanics compared with the first generation of RSA. As the concept, design, and surgical technique of RSA continue to improve, the rates and types of complications may change over time. One study noted that after implant modifications, there have been statistically significant declines in baseplate failure, humeral dissociation, and glenosphere dissociation.[191]

As the indications and use of RSA continue to expand, it is important to track the rates and types of complications as the procedure continues to develop over time. The purpose of this 2-part study was to provide a focused systematic review of the most common complications of RSA using contemporary prosthetic designs, therefore limiting studies to those published in 2010 or later. In this part (part I), we performed a systematic review of (1) scapular notching (SN), (2) periprosthetic infection (PJI), (3) mechanical failure (glenoid component [GC] and humeral component [HC]), and (4) neurologic injury (NI). Part II covers (1) instability; (2) humeral or glenoid fractures; (3) acromial or scapular spine fractures; and (4) problems or miscellaneous, including complex regional pain syndrome, deltoid injury, hematoma, and heterotopic ossification. We established a study design and specific objectives before commencing each literature research.

Scapular notching

Methods

A systematic review was performed using Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[139] The search was performed using the PubMed medical database in February 2019 (Fig. 1). The search terms used were ((scapular notching) OR (notching) AND (reverse shoulder arthroplasty) OR (reverse total shoulder) OR (reverse total shoulder arthroplasty)) with filters as follows: date range of January 1, 2010, to December 31, 2018; human species; and English language. The search resulted in 902 total titles. One author (S.S.S.) then reviewed the titles. The inclusion criteria were titles that specified primary or revision RSA. The exclusion criteria were duplicate titles; review

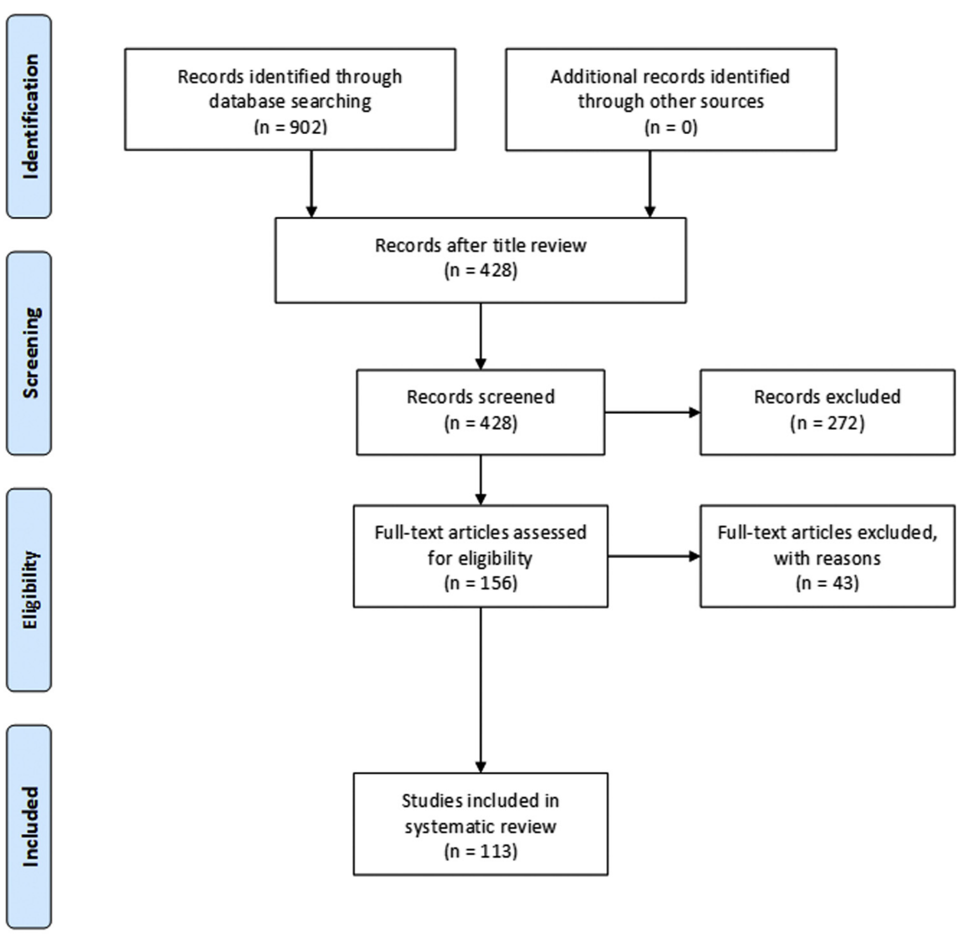

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-analyses diagram for scapular notching.

Table I
Scapular notching rates overall and stratified by grade

	Studies included	Shoulders	Scapular notching present	Rate, % (n)
Overall	113	8258	2431	29.43 (2431 of 8258)
Stratified by grade	94	6898	2086	—
Grade I	—	—	1206	57.81 (1206 of 2086)
Grade II	—	—	460	22.05 (460 of 2086)
Grade III	—	—	274	13.13 (274 of 2086)
Grade IV	—	—	146	7.0 (146 of 2086)

The majority of notches (79.87% [1666 of 2086]) were classified as low grade (grade I or II).

Table II
Rates of scapular notching according to publication date (2010-2015 vs. 2016-2018), average follow-up time (<5 years vs. ≥5 years), revision status (primary vs. revision RSA), and center of rotation

	Studies included	Shoulders	Scapular notching present	Rate, %	*P* value
Year published					<.001
2010-2015	62	3707	1342	36.2	
2016-2018	51	4551	1089	23.9	
Follow-up					<.001
≥5 yr	17	947	411	43.4	
<5 yr	96	7311	2020	27.6	
Primary vs. revision RSA					<.001
Primary	71	5680	1594	28.1	
Revision	17	728	374	51.4	
Center of rotation					<.001
Medialized	84	5913	1953	33.0	
Lateralized	14	1281	285	22.2	

RSA, reverse shoulder arthroplasty.

articles; editorials; technique articles without reported patient outcomes; cadaveric studies; kinematic, finite element model, or computer model analyses; case reports; survey studies; elastography or histologic studies; cost-benefit analyses; and instructional course lecture articles. After application of these criteria, 428 titles remained for abstract review. Articles that reported 2-year radiographic follow-up, complications, or outcomes and/or notching or SN were included. We excluded case series with ≤20 patients at final follow-up; nonclinical studies; studies not related to RSA; studies with an average follow-up period < 24 months; studies that included patients who underwent concomitant tendon transfer, evaluated treatment of shoulder PJI, or reported only clinical outcomes or range of motion; and studies of RSA for an indication of tumor. This process eliminated 272 more articles, leaving 156 for full-text review. Articles that did not report SN rates or that reported incomplete SN rates were also excluded in the full-text review. The definition of SN was left to the discretion of each study. This final elimination stage resulted in 113 articles for inclusion in the analysis.

The rates of SN overall and according to (1) revision status (primary vs. revision arthroplasty), (2) publication date (2010-2015 vs. 2016-2018), (3) average follow-up time (<5 years vs. ≥5 years), (4) center of rotation (CoR) (medialized vs. lateralized), and (5) prosthesis design were determined by pooled statistics. CoR and prosthesis design were defined according to Routman et al,[171] who stated that a glenosphere with a CoR ≤ 5 mm to the glenoid face is considered an MG and a glenosphere with a CoR > 5 mm lateral to the glenoid face is considered a lateralized glenoid (LG). Of note, revision RSA included both failed arthroplasty (hemiarthroplasty, anatomic total shoulder arthroplasty [TSA], or RSA) and failed open reduction−internal fixation of PHF. Comparisons were also made to the study of Zumstein et al.[223]

Statistical analysis was performed using SPSS software (version 26; IBM, Armonk, NY, USA). Univariate analysis was performed with the χ^2 test or, when the expected count for ≥1 cell in the comparison was <5, with the Fisher exact test. The α level for statistical significance was set to .05.

Results

Regarding the level of evidence, the majority of the studies were level IV (73) or III (36) studies, with only 1 level II and 3 level I studies.* A total of 8258 shoulders were included in the analysis, with a mean age of 70.1 years and 66.9% of female sex. The overall SN rate was 29.4% (2431 of 8258 shoulders) at a mean follow-up of 3.5 years. Stratification by grade showed 1206 grade I, 460 grade II, 274 grade III, and 146 grade IV notches when statistics were pooled from the 94 studies (2086 shoulders) that defined the gradation of notching. Of note, 79.9% of notches (1666 of 2086) were classified as low-grade SN (grade I or II) (Table I). In total, 17 different implant systems were encountered. Primary RSA had an SN rate of 28.1% (1594 of 5680) vs. 51.4% (374 of 728) for revision RSA (P < .001) (Table II). The Grammont design (MG or MH) had a higher notching rate vs. all other designs combined (42.5% vs. 12.3%, P < .001). The MG or LH design had a lower rate vs. the LG or MH design (10.5% vs. 14.8%, P < .001). Notching rates, especially those for non-Grammont modern designs, have decreased compared with the findings of Zumstein et al[223] (Table III).

Periprosthetic infection

Methods

A systematic review was performed using PRISMA guidelines.[139] The search was performed using 2 common medical databases,

* 1-5, 7-12, 15, 17, 18, 21, 24, 25, 28, 31, 32, 35, 36, 38, 39, 43, 45, 46, 52, 54, 55, 58-60, 65, 66, 69, 71-74, 77, 78, 84-90, 92-97, 100-102, 104, 106, 107, 109, 114, 117, 119, 128-137, 140-143, 145, 147, 149, 152, 155, 160-163, 166, 168, 170, 172, 174, 175, 177, 179, 181-183, 186, 189, 192, 194-196, 198-200, 203, 204, 209, 211, 214, 215, 218

Table III
Rates of scapular notching according to prosthesis design

	Studies included	Shoulders	Scapular notching present	Rate, %	*P* value
Prosthesis design					
LG or MH	15	1002	148	14.8	.001* vs. MG or LH .91 vs. LG or LH <.001* vs. MG or MH
MG or LH	11	1730	181	10.5	.02* vs. LG or LH <.001* vs. MG or MH
LG or LH	5	279	42	15.0	<.001* vs. MG or MH
Subtotal	31	3011	371	12.3	<.001* vs. MG or MH
MG or MH	71	4115	1750	42.5	—
Author					
Zumstein et al[223]	21	782	277	35.4	—
Current study	113	8258	2431	29.4	<.001* vs. Zumstein et al
Subtotal of non-Grammont designs in current study	31	3011	371	12.3	<.001* vs. Zumstein et al

LG, lateralized glenoid; *MH*, medialized humerus; *MG*, medialized glenoid; *LH*, lateralized humerus.
The Grammont design (MG or MH) had a higher notching rate vs. all other designs combined (42.5% vs. 12.3%, $P < .001$). The MG or LH design had a lower rate vs. the LG or MH design (10.5% vs. 14.8%, $P < .001$). Notching rates, especially for non-Grammont modern designs, have decreased compared with the findings of Zumstein et al (*Journal of Shoulder and Elbow Surgery*, 2011).
* Statistically significant ($P < .05$).

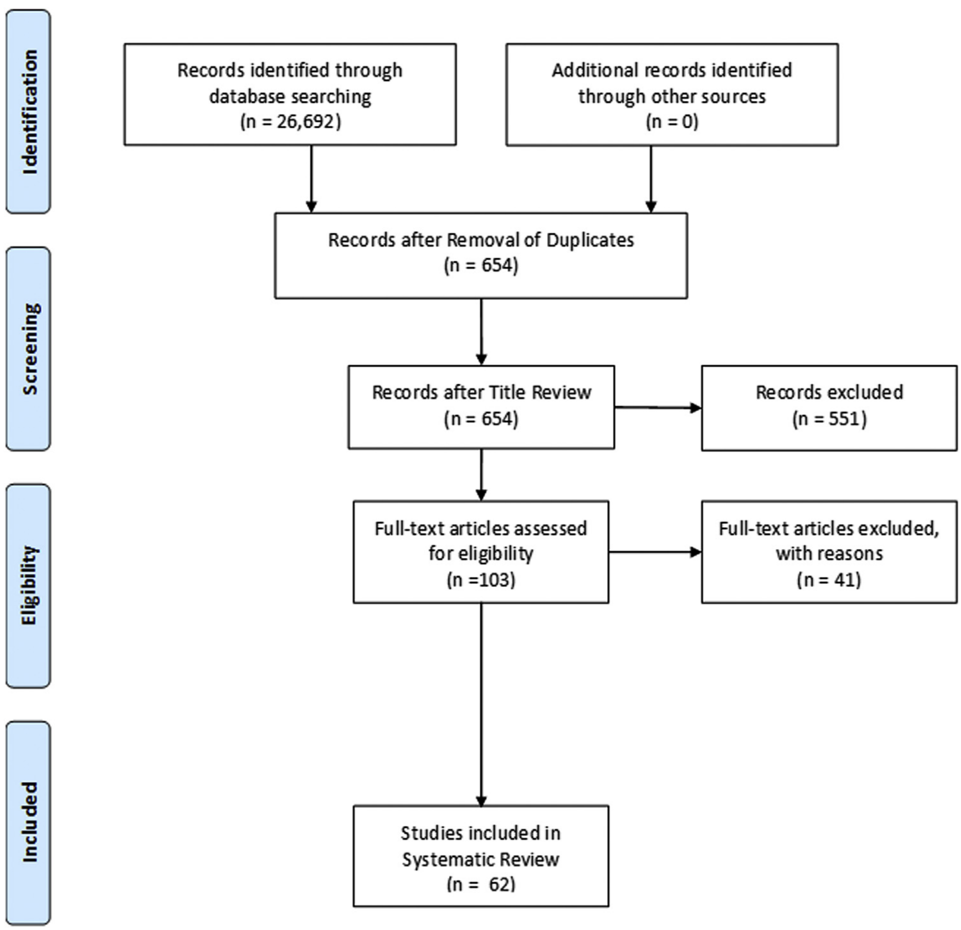

Figure 2 Preferred Reporting Items for Systematic Reviews and Meta-analyses diagram for periprosthetic infection.

PubMed and Embase, on May 15, 2018 (Fig. 2). The search terms used were “reverse shoulder arthroplasty” and “reverse ball and socket” in the English-language literature. The search resulted in 26,692 total titles. One author (S.N.) then reviewed the titles. The inclusion criteria were titles that specified primary or revision RSA. The exclusion criteria were duplicate titles, review articles, editorials, technique articles without reported patient outcomes, and instructional course lecture articles. After application of these criteria, 654 titles remained for abstract review. We excluded articles that were case series with <10 patients, were not related to RSA, had a minimum average follow-up period < 24 months, included patients who underwent concomitant tendon transfer, or evaluated RSA for an indication of tumor. This process eliminated 551 more articles, leaving 103 for full-text review. Articles that did

Table IV
Periprosthetic infection rates overall and stratified by diagnosis

	Studies included	Shoulders	Periprosthetic infection present	Rate, %	*P* value
Primary vs. revision RSA					
Primary	45	3065	73	2.4	.73
Revision	20	1331	34	2.6	
Diagnosis					
CTA or irreparable RCT	29	2575	64	2.4	.07 vs. acute Fx .30* vs. Fx sequelae
Acute Fx	10	329	3	0.9	.07* vs. Fx sequelae
Fx sequelae	7T	161	6	3.7	—
Author					
Zumstein et al[223]	21	782	30	3.8	.02
Current study	65	4396	107	2.4	

RSA, reverse shoulder arthroplasty; *CTA*, cuff tear arthropathy; *RCT*, rotator cuff tear; *Fx*, fracture.
Periprosthetic infection rates have decreased compared with the findings of Zumstein et al.
* Fisher exact test comparison.

not report infection rate by indication for RSA were also excluded in the full-text review. Given the few studies that evaluated diagnoses of instability and OA without rotator cuff tear, these diagnoses were eliminated. The definition of PJI was left to the discretion of each study. This final elimination stage resulted in 62 articles for inclusion in the analysis. The rate of PJI after primary and reverse arthroplasty was determined by pooled statistics. Comparisons were also made to the study of Zumstein et al.[223]

Statistical analysis was performed using SPSS software (version 26). Univariate analysis was performed with the χ^2 test or, when the expected count for ≥1 cell in the comparison was <5, with the Fisher exact test. The α level for statistical significance was set to .05.

Results

Regarding the level of evidence, the vast majority of the studies were level IV or III studies.[†] A total of 4396 patients were included in the analysis at a mean of 4.1 ± 2.4 years' follow-up. There were 3065 primary arthroplasties and 1331 revision arthroplasties. Diagnoses in reverse arthroplasty cases included rotator cuff tear arthropathy (CTA) or irreparable rotator cuff tear (n = 2575), acute PHF (n = 329), or sequelae of PHF (n = 161). The PJI rate was 2.4% (73 of 3065) at a mean follow-up of 4.3 years when statistics were pooled from the 45 studies evaluating primary RSAs. When stratified by diagnosis, the PJI rate was 2.4% (64 of 2575) for CTA or irreparable rotator cuff tear (29 studies), 0.9% (3 of 329) for acute fractures (10 studies), and 3.7% (6 of 161) for fracture sequelae (7 studies). The PJI rate was 2.6% (34 of 1331) at a mean follow-up of 3.8 years when statistics were pooled from the 20 studies evaluating revision RSAs. PJI rates have decreased compared with the findings of Zumstein et al[223] (2.4% vs. 3.8%, $P = .02$) (Table IV).

Mechanical failure

Methods

A systematic review was performed using PRISMA guidelines.[139] The search was performed using the PubMed medical database in February 2018 (Fig. 3). The search terms used were ((mechanical complications OR complications OR lucent lines OR radiolucency OR loosening OR glenoid loosening OR humeral loosening OR glenosphere dislocation OR polyethylene dissociation OR polyethylene wear OR screw breakage OR screw loosening) AND (reverse shoulder arthroplasty OR reverse total shoulder OR reverse total shoulder arthroplasty)) with filters as follows: date range of January 1, 2010, to December 31, 2017; human species; and English language. The search resulted in 433 total titles. One author (B.M.G.) then reviewed the titles. The inclusion criteria were studies with ≥50 patients, studies with minimum 2-year clinical and radiographic follow-up, and studies that clearly reported at least one of the following mechanical complications: GC radiolucent lines, GC loosening, GC loosening requiring revision, HC radiolucent lines, HC loosening, or HC loosening requiring revision. The exclusion criteria were studies that did not include ≥50 patients, did not report radiographic results, were not clinical studies, or included TSA patients. After application of these criteria, the abstracts were reviewed. This process left 125 articles for full-text review. Articles that did not have 2-year radiographic follow-up, included <50 patients with 2-year radiographic follow-up, or did not differentiate between prosthetic component dislocation and joint dislocation were also excluded in the full-text review. The definition of mechanical failure on the glenoid or humerus was left to the discretion of each study. This final elimination stage resulted in 34 articles for inclusion in the analysis. Comparisons were made to the study of Zumstein et al.[223]

Statistical analysis was performed using SPSS software (version 26). Univariate analysis was performed with the χ^2 test or, when the expected count for ≥1 cell in the comparison was <5, with the Fisher exact test. The α level for statistical significance was set to .05.

Results

The studies were mostly retrospective and provided level III or IV evidence.[‡] CTA (n = 23) and massive rotator cuff tears (n = 3) were the primary indications for surgery in 26 of the included studies. In 6 studies, the operations were primarily revisions. The number of shoulders included from each study ranged from 50 to 591, and the pooled total was 4825 shoulders. Data on the age of the included patients were available from 30 studies, and the mean age ranged from 48 to 76 years. The mean follow-up period ranged from 26 to 115 months. There were 14 different implants used in 22 of the studies; in the remaining 12 studies, either the implant type was not reported or multiple implants were used but not stratified based on mechanical complications.

The incidence of radiolucent lines around the GC was reported in 12 studies. The incidence ranged from 0% to 60%; 5 studies

† 4, 8, 19, 20, 22, 24, 26, 29, 37, 38, 39, 41, 51, 54, 59, 62, 64-67, 80, 81, 94, 99, 101, 113, 115-118, 121, 127, 129, 132, 133, 135, 142, 155, 163, 165, 167, 170, 173, 176, 181, 182, 195, 197, 199, 203, 206, 207, 209, 211-213, 215, 216, 219, 222

‡ 12, 15, 37, 38, 46, 58, 59, 65, 68, 82, 88, 102, 103, 114, 117, 130, 134, 135, 140, 143, 155, 158, 176, 179, 191, 194, 195, 199, 202, 205, 208, 211, 215, 221

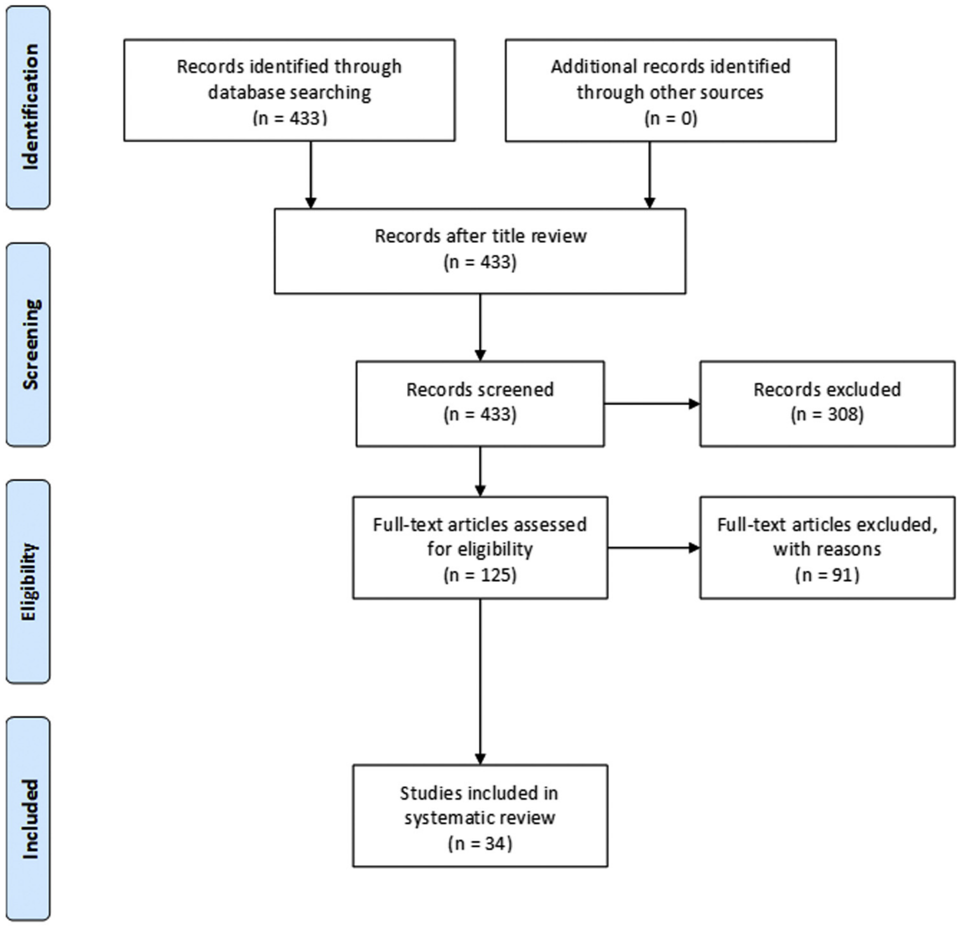

Figure 3 Preferred Reporting Items for Systematic Reviews and Meta-analyses diagram for mechanical failure.

reported a rate of 0%, whereas the others reported rates of 1%, 3%, 7%, 10%, 12%, and 60% (pooled mean incidence, 7.7% [103 of 1336]). The rate of GC loosening was reported by 30 studies, and the mean incidence ranged from 0% to 14%, with a pooled mean incidence of 2.3% (89 of 3995). Although there was a higher reported rate of radiolucent lines present, the rate of GC loosening was decreased compared with the findings of Zumstein et al[223] (2.3% vs. 3.5%, $P =$ .04). The pooled mean incidence of revision for loosening was 2.1% (69 of 2908), with a range of 0% to 14%, based on data available from 26 studies (Table V).

The incidence of radiolucent lines around the HC was reported by 18 studies. The incidence ranged from 0% to 57%, with a pooled mean incidence of 12% (292 of 2419). The rate of HC loosening was reported by 29 studies, with a mean incidence that ranged from 0% to 12% (pooled mean, 1.4% [52 of 3817]). The revision rate for HC loosening was reported by 26 studies and ranged from 0% to 12%, with a pooled mean incidence of 1% (30 of 2920) (Table V).

Neurologic injury

Methods

A systematic review was performed using PRISMA guidelines.[139] The search was performed using the PubMed medical database in March 2019 (Fig. 4). The search terms used were ((neurological injury) OR (complication) OR (axillary nerve) OR (iatrogenic nerve injuries) OR (nerve injury) OR (suprascapular nerve) OR (radial nerve) OR (musculoskeletal nerve) AND (reverse shoulder arthroplasty) OR (reverse total shoulder) OR (reverse total shoulder arthroplasty)) with filters as follows: date range of January 1, 2010, to December 31, 2018; human species; and English language. The search resulted in 930 total titles. The inclusion criteria were titles that specified primary or revision RSA. The exclusion criteria were review articles; systematic reviews; editorials; technique articles without reported patient outcomes; cadaveric studies; kinematic, finite element model, or computer model analyses; case reports; survey studies; elastography or histologic studies; cost-benefit analyses; and instructional course lecture articles. After application of these criteria, 230 titles remained for abstract review. Articles were included if they reported complication data and/or reported neurologic or nerve injury, axillary nerve injury, iatrogenic nerve injury, suprascapular nerve injury, radial nerve injury, or musculoskeletal nerve injury. We excluded studies with <15 patients; studies not related to RSA; studies with an average follow-up period < 24 months; and studies that investigated patients who underwent concomitant tendon transfer or evaluated treatment of PJI, blood transfusion rates, venous thromboembolism rates, or RSA for tumor. This process eliminated 165 more articles, leaving 65 for full-text review. Articles that recycled patient data from already-included studies, did not differentiate between anatomic TSA and RSA patients, or did not have 2-year follow-up data on complications were also excluded in the full-text review. This final elimination stage resulted in 48 articles for inclusion in the analysis. The definition of NI was left to the discretion of each study. Two authors (B.T.G. and S.S.S.) reviewed the articles and collected the data.

The rates of NI overall and according to (1) revision status (primary vs. revision arthroplasty), (2) publication date (2010-2015

Table V
Pooled estimates of mechanical complications following RSA

	Component		Author	
	Glenoid	Humeral	Zumstein et al[223]	Current study
Radiolucent lines, % (n)	7.7 (103 of 1336)	12 (292 of 2419)		
Loosening, % (n)	2.3 (89 of 3995)	1.4 (52 of 3817)		
Revision for loosening, % (n)	2.1 (62 of 2908)	1 (30 of 2920)		
Glenoid radiolucent lines				
Studies included			21	12
Shoulders			782	1336
Glenoid radiolucent lines present			23	103
Rate, %			2.9	7.7
P value				<.001
Glenoid loosening				
Studies included			21	30
Shoulders			782	3995
Glenoid loosening present			27	89
Rate, %			3.5	2.3
P value				.04
Humeral loosening				
Studies included			21	29
Shoulders			782	3817
Humeral loosening present			10	52
Rate, %			1.3	1.4
P value				.85

RSA, reverse shoulder arthroplasty.
Although there was a higher reported rate of radiolucent lines present, the rate of glenoid component loosening was decreased compared with the findings of Zumstein et al (*Journal of Shoulder and Elbow Surgery*, 2011) (2.3% vs. 3.5%, $P = .04$). Of note, humeral component radiolucent lines were not reported in the study of Zumstein et al.

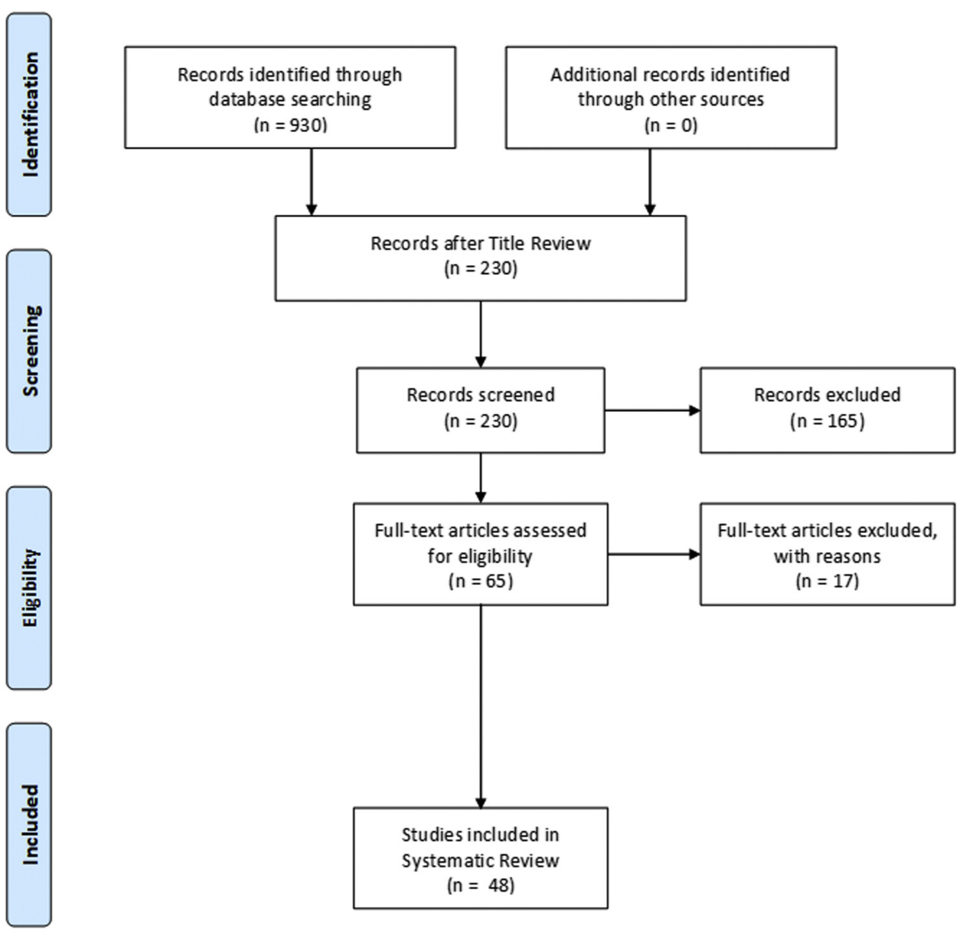

Figure 4 Preferred Reporting Items for Systematic Reviews and Meta-analyses diagram for neurologic injury.

Table VI
Neurologic injury rates overall and stratified by prosthesis design, year published, and specific nerve

	Studies included	Shoulders	Neurologic injury reported	Rate, % (n)	*P* value
Overall	48	4135	23	0.6 (23 of 4135)	
Stratified by specific nerve	45	2559	14	—	
Axillary nerve	—	—	8	57.2 (8 of 14)	
Musculoskeletal nerve	—	—	2	14.3 (2 of 14)	
Suprascapular nerve	—	—	1	7.1 (1 of 14)	
Radial nerve	—	—	2	14.3 (2 of 14)	
Ulnar nerve	—	—	1	7.1 (1 of 14)	
Prosthesis design					
LG or MH	—	464	1	0.2	—
MG or LH	—	269	0	0.0	—
LG or LH	—	17	0	0.0	—
Subtotal	12	750	1	0.1	.04*,† vs. MG or MH
MG or MH	31	1425	13	0.9	—
Year published					
2010-2015	26	2596	16	0.6	.5
2016-2018	22	1539	7	0.5	

LG, lateralized glenoid; *MH*, medialized humerus; *MG*, medialized glenoid; *LH*, lateralized humerus.
The Grammont design (MG or MH) had an increased neurologic injury rate vs. all other designs combined (0.9% vs. 0.1%, *P* = .04).
* Fisher exact test comparison.
† Statistically significant (*P* < .05).

vs. 2016-2018), (3) diagnosis, (4) CoR, and (5) prosthesis design were determined by pooled statistics. CoR and prosthesis design were defined according to Routman et al.[171] Of note, revision RSA included failed arthroplasty (hemiarthroplasty, TSA, or RSA) and failed open reduction–internal fixation of PHF. Comparisons were also made to the study of Zumstein et al.[223]

Statistical analysis was performed using SPSS software (version 26). Univariate analysis was performed with the χ^2 test or, when the expected count for ≥1 cell in the comparison was <5, with the Fisher exact test. The α level for statistical significance was set to .05.

Results

The studies were mostly retrospective and provided level III evidence (10 studies) or level IV evidence (36 studies), with 2 studies providing level II evidence.[§] A total of 4135 shoulders were included in the analysis, with a mean age of 70.3 years. The overall rate of NI was 0.6% (23 of 4135 RSAs) at a weighted mean follow-up of 3.4 years; 72.9% of patients were female patients. The majority of reported neurologic complications involved the axillary nerve (57.2%), followed by the musculoskeletal nerve (14.3%) and radial nerve (14.3%). The Grammont design (MG or MH) had an increased NI rate vs. all other designs combined (0.9% vs. 0.1%, *P* = .04) (Table VI). Primary RSA had a decreased rate of NI compared with revision (0.4% vs. 1.1%, *P* = .03). The subtotal of non-Grammont designs in this study had a decreased rate of NI vs. the findings of Zumstein et al[223] (0.1% vs. 1.2%, *P* = .02) (Table VII).

Discussion

RSA has demonstrated good clinical outcomes at long-term follow-up,[53] leading to expanding indications and wider adoption. Authors have reported good results in patients aged < 55 years,[155] patients aged > 65 years who have OA with an intact rotator cuff,[190,193] and complex salvage-type clinical situations such as revision for a failed primary RSA.[204] It has even proved cost-effective in instances such as complex PHFs in elderly patients.[154]

As the indications continue to expand, it is imperative to accurately track the rates and types of complications to justify the cost. By limiting each search to publications in 2010 or later and by performing a systematic review of each complication, our study was able to examine large sample sizes and provide useful analyses based on diagnosis and prosthesis design that are typically difficult with registry studies or case series. Registry studies have large sample sizes but classically report only revision rates and lack data on specific complication rates without revision.[110,138] By contrast, case series usually lack large sample sizes that are necessary to make specific comparisons with increased power. Our findings will allow for better patient education and be helpful for surgeon planning for RSA based on diagnosis and prosthesis design.

On the basis of this study, the global SN rate was 29.4% (2431 of 8258) at a mean follow-up of 3.5 years. When stratified by grade, 79.9% of notches were classified as low-grade SN (grade I or II). However, there are multiple variables that may play a role: patient anatomy,[157,194] surgical approach leading to variable exposure for placement of the baseplate,[2] length of follow-up,[114,141] glenosphere size,[196] eccentric glenosphere,[119] inferior glenosphere overhang,[47,150,160] and implant design.[16] A randomized controlled trial showed that an overarching theme to minimize notching is an inferior glenosphere overhang > 3.5 mm[160]; glenosphere size, eccentric placement, and surgical technique are all options to achieve the same goal of an inferior overhang to minimize notching. When stratified by prosthesis design, the Grammont design (MG or MH) had a significantly higher notching rate vs. all other designs combined (42.5% vs. 12.3%, *P* < .001). The MG or LH design had the lowest rate, which was significantly lower vs. the LG or MH design as well. Notching rates, especially those of non-Grammont modern designs, were significantly decreased compared with the findings of Zumstein et al.[223]

Although severe notching plays a role in glenoid baseplate stability,[169] the effect of less severe notching on clinical outcomes remains controversial. In their series of 461 shoulders, Lévigne et al[114] found no relationship between SN and pain or the Constant-Murley score. In a more recent series of 476 shoulders, Mollon et al[141] found significantly lower postoperative Shoulder Pain and Disability Index and Constant-Murley scores in patients with SN than in patients without any notching. Furthermore, patients with SN were found to have significantly lower active abduction or forward flexion, less strength, and significantly higher complication rates.

§ 12, 18, 19, 23, 39, 42, 52, 54, 58, 59, 63, 66, 67, 71, 72, 76, 79, 82, 85, 86, 92, 99, 102, 105, 122, 124, 125, 127, 132, 148, 149, 153, 155, 164, 166, 177, 180, 182, 185, 189, 197, 198, 201, 204, 209, 211, 215, 220

Table VII
Rates of neurologic injury rates according to publication date (2010-2015 vs. 2016-2018), diagnosis, revision status (primary vs. revision RSA), and center of rotation

	Studies included	Shoulders	Neurologic injury reported	Rate, %	*P* value
Diagnosis					
CTA	—	476	2	0.4	—
RCT and OA	—	470	2	0.4	—
Proximal humeral fracture	—	284	1	0.4	—
Subtotal	—	1230	5	0.4	.19* vs. RA .05 vs. FA
RA	—	45	1	2.2	—
FA	—	777	9	1.2	.43* vs. RA
Primary vs. revision RSA					
Primary	—	3275	13	0.4	.03*,†
Revision	—	845	9	1.1	—
Center of rotation					
Medialized	34	1694	13	0.8	.33*
Lateralized	10	481	1	0.2	—
Author					
Zumstein et al[223]	21	782	9	1.2	.06
Current study	48	4135	23	0.6	
Subtotal of non-Grammont designs in current study	12	750	1	0.1	.02*,† vs. Zumstein et al

RSA, reverse shoulder arthroplasty; *CTA*, cuff tear arthropathy; *RCT*, massive rotator cuff tear; *OA*, osteoarthritis; *RA*, rheumatoid arthritis; *FA*, failed arthroplasty.
Primary RSA had a decreased rate of neurologic injury (0.4% vs. 1.1%, $P = .03$). The subtotal of non-Grammont designs had a decreased rate of neurologic injury vs. the findings of Zumstein et al (0.1% vs. 1.2%, $P = .02$).
* Fisher exact test comparison.
† Statistically significant ($P < .05$).

On the basis of this study, the PJI infection rate was 2.4% (73 of 3065) at a mean follow-up of 4.3 years for primary RSA cases. The rate was 2.6% (34 of 1331) at a mean follow-up of 3.8 years for revision arthroplasty cases, which is comparable to the 2.8% PJI rate for revision cases found in a recent review.[27] Although the reported PJI rate is significantly lower than that of Zumstein et al,[223] the reported rate of infection for RSA is still higher than that for anatomic shoulder arthroplasty. In a study with a similarly large cohort, the rate of infection for primary anatomic shoulder replacement was 0.5% (24 of 3014 cases).[48] Factors that may explain the RSA infection rate include an increased implant surface, a large subacromial dead space, the compromised general health of some patients, and the complexity of some indications.[34] Additionally, as in previous studies,[210,223] there was a trend toward higher infection rates in revision surgery groups compared with primary arthroplasty groups.

On the basis of this study, the pooled mean incidence of radiolucent lines and loosening around the GC was 7.7% and 2.3%, respectively. Although there was a higher reported rate of radiolucent lines present, the rate of GC loosening was significantly decreased compared with the findings of Zumstein et al.[223] The pooled mean revision rate for GC loosening was 2.1% (69 of 2908). The pooled mean incidence of radiolucent lines around the HC was 12% (292 of 2419). The pooled mean incidence of HC loosening was 1.4% (52 of 817). The pooled mean revision rate for HC loosening was 1% (30 of 2920).

Because of the forces occurring at the glenoid, most early reports were wary of loosening. Significant mechanical stress at the bone-implant interface may influence bony ingrowth and may impact long-term stability.[75] Our observed lower rate of GC loosening compared with the findings of Zumstein et al[223] may be ascribed to significant advancements in biomaterials. Although lateralized RSA designs have potentially greater loads transferred to the bone-prosthesis interface[184] and premature mechanical failure due to loosening is a concern with these devices,[217] the addition of locking-screw technology, as well as hydroxyapatite coating, and the increased size (5 mm) of peripheral screws have significantly reduced the rate of baseplate failure of a specific lateralized RSA design.[40,144] To avoid loosening, every effort should be made to optimally fix the GC onto good bone stock at the inferior border of the glenoid.[151]

The rate of HC loosening in our study was similar to the findings of Zumstein et al.[223] In the modern RSA, mainly uncemented HCs are being used in the primary setting. There has been concern that uncemented stems lead to proximal bone resorption and stress shielding; however, early cementless shoulder arthroplasty designs used smooth, press-fit fixation relying on diaphyseal fixation. Current designs incorporate on-growth or ingrowth surfaces and rely on metaphyseal fixation. Advantages of metaphyseal fixation include better vascularity potentially allowing more rapid ingrowth, easier stem removal during revision, and reduced rates of stress shielding.[98] Additionally, Wiater et al[215] have shown similar clinical and radiologic outcomes in a cohort study comparing patients with cemented and cementless HCs in RSA. Generally, aseptic loosening of the HC is uncommon; infection should also always be suspected as the etiologic source of loosening, and the patient should be managed accordingly.[50]

On the basis of this study, the overall incidence of neurologic complications was 0.6% (23 of 4135 RSAs) at a mean follow-up of 3.4 years. In this study, the Grammont design had a significantly increased NI rate vs. all other designs combined. Primary RSA had a statistically higher NI incidence vs. revisions. An NI rate for revision RSA of 1.1% is consistent with the recent literature.[27] The subtotal of non-Grammont designs had a significantly decreased rate of NI vs. the findings of Zumstein et al.[223] The majority of reported NIs involved the axillary nerve, followed by the suprascapular nerve and radial nerve. Placement of an RSA can threaten the axillary nerve because of its proximity to the humeral metaphysis (average distance in cadaveric study, 8.1 mm) and the inferior glenoid rim (average distance, 13.6 mm).[112] Some authors have suggested that surgeons should routinely palpate or expose the axillary nerve during shoulder arthroplasty in an effort to avoid injury.[33,61] However, LiBrizzi et al[120] demonstrated that a low incidence of partial temporary isolated axillary nerve injury (0.7%) can be expected without routine identification of the nerve. Furthermore, posterior and superior drilling for screw placement during baseplate implantation places the suprascapular nerve at risk. The distance from the center of the glenoid to the suprascapular nerve under the transverse scapular ligament is 28.4 mm and the distance to the spinoglenoid notch is 16.6 mm, both when measured in the mediolateral direction.[112]

Subclinical NIs by means of intraoperative neuromonitoring[159] or postoperative electromyographic changes[108] are common after RSA, whereas the incidence of clinically evident NI is quite rare. Another consideration is that they may be under-reported secondary to spontaneous recovery in many cases.[13] Although neurologic complications are considered rare and transient, they may affect the clinical outcome (ie, secondary to decreased deltoid strength from axillary nerve deficit[26]) and may necessitate operative intervention, that is, neurolysis[132] or baseplate screw removal.[19] Indirect traction injuries are thought to be the main culprit for these lesions secondary to arm lengthening[108] and/or external rotation during humeral and glenoid preparation.[159] Avoidance of prolonged periods in these at-risk arm positions, along with intermittent recovery phases in the neutral position, may prove beneficial to decrease the rate of nerve injury.[13,146,159] Moreover, anatomic studies have shown that lateralization is less harmful in terms of stretch on the axillary nerve vs. distalization.[126] Along these lines, prostheses with a lateralized CoR in our study demonstrated a 0.2% NI rate vs. 0.8% in RSAs with a medialized CoR, but the difference was not statistically significant.

The limitations of this study are similar to those of any systematic review, including many retrospective studies with possible reporting bias, differing follow-up times, publication bias, and possible conflicting definitions of complications among studies. Furthermore, the complication rates in this study are only based on published data predominantly from high-volume centers; this may not capture the rate or distribution of complications in the general population treated by surgeons elsewhere, “many of whom perform only a few of these procedures each year.”[188] High-volume centers have been reported to have better perioperative quality metrics[187] and maximized outcomes after RSA, likely related to surgical experience.[56] Thus, it has been advised that complex procedures such as RSA be performed at high-volume destinations, and lower-volume institutions have been encouraged to strategize to function as higher-volume centers.[56] Another limitation is that patient outcomes were not collected; however, our study was able to examine multiple complications with large sample sizes and provide useful analyses based on diagnosis and prosthesis design that are difficult with registry studies (secondary to lack of specific data) or case series, as many lack the large sample sizes necessary to make comparisons with clinical value.

Conclusion

Focused systematic reviews of the recent literature with a large volume of RSAs demonstrate that with the use of non-Grammont modern prosthesis designs, complications including SN, PJI, GC loosening, and NI are significantly reduced compared with previous studies. As the indications for RSA continue to expand, it is imperative to accurately track the rates and types of complications to justify its cost and increased indications.

Disclaimer

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