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

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Background: Globally, reverse shoulder arthroplasty (RSA) has moved away from the Grammont design to modern prosthesis designs. The purpose of this study was to provide a focused, updated systematic review for each of the most common complications of RSA by limiting each search to publications after 2010. In this part II, the following were examined: (1) instability, (2) humerus/glenoid fracture, (3) acromial/scapular spine fractures (AF/SSF), and (4) problems/miscellaneous.

Methods: Four separate PubMed database searches were performed following Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Overall, 137 studies for instability, 94 for humerus/glenoid fracture, 120 for AF/SSF, and 74 for problems/miscellaneous were included in each review, respectively. Univariate analysis was performed with chi-square and Fisher exact tests.

Results: The Grammont design had a higher instability rate vs. all other designs combined (4.0%, 1.3%; $P < .001$), and the onlay humerus design had a lower rate than the lateralized glenoid design (0.9%, 2.0%; $P = .02$). The rate for intraoperative humerus fracture was 1.8%; intraoperative glenoid fracture, 0.3%; postoperative humerus fracture, 1.2%; and postoperative glenoid fracture, 0.1%. The rate of AF/SSF was 2.6% (371/14235). The rate for complex regional pain syndrome was 0.4%; deltoid injury, 0.1%; hematoma, 0.3%; and heterotopic ossification, 0.8%.

Conclusions: Focused systematic reviews of recent literature with a large volume of shoulders demonstrate that using non-Grammont modern prosthesis designs, complications including instability, intraoperative humerus and glenoid fractures, and hematoma are significantly reduced compared with previous studies. As the indications continue to expand for RSA, it is imperative to accurately track the rate and types of complications in order to justify its cost and increased indications.

Although initially indicated for patients with rotator cuff arthropathy,[18,89] reverse shoulder arthroplasty (RSA) indications have recently expanded to include osteoarthritis with an intact rotator cuff[286] as well as tumor resection, postinfectious sequelae,[57] chronic dislocations, and revisions of failed arthroplasties.[24] RSA is frequently used to treat difficult clinical diagnoses; consequently, it is not surprising to see a relatively high complication rate. Reports have concluded that indications such as rheumatoid arthritis have a higher risk of intraoperative and postoperative fracture[290] and that prior nonarthroplasty shoulder surgery confers a higher complication rate post RSA compared with those with no prior surgery on the ipsilateral shoulder.[76]

The use of RSA has continued to rise, and it has become the majority shoulder arthroplasty since 2016. It has had an even more profound effect on revision shoulder arthroplasty than what

Institutional Review Board approval was not required for this systematic review.

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previously has been documented in the primary setting.[263] Thus, precise knowledge of the probability and implications of the various complications are imperative for judicious use of RSA.[70] Complications have been well described; the studies in the literature, however, are heterogeneous (eg, different indications, different prostheses, and different populations) and definitions vary between authors.[39,293] 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.[214] Patient factors including smoking status,[104] diabetes,[159] Parkinson disease,[33] and preoperative American Society of Anesthesiologists score[121] have all been linked to increased complications and/or unfavorable outcomes. Some advocate that primary shoulder arthroplasty is performed more efficiently by higher-volume surgeons,[235] and complications have been reported to decrease with surgeon experience.[269] Recent data have defined a volume-outcome relationship where, likely related to surgical experience, ancillary staff familiarity, and protocolized pathways, hospital surgical volumes of 54-70 RSAs/yr correlate with the highest outcomes.[69]

The majority of the published studies on RSA have historically reported on a Grammont-style RSA (glenosphere with medialized center of rotation [MG] along with an inlay humeral component that medializes the 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 humeral-based lateralization (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.[240] Further, a recent study noted that primary RSA performed with contemporary implants and surgical techniques seems to be associated with a very low rate of reoperation.[126]

As the indications and use of RSA continue to expand, it is important to track the rate and types of complication as the procedure continues to develop over time. The purpose of this 2-part study was to provide a focused systematic review for the most common complications of RSA using contemporary prosthetic designs, therefore limiting studies to those published after 2010. In this part II, a systematic review was performed for (1) instability, (2) humerus/glenoid fracture, (3) acromial/scapular spine fractures, and (4) problems/miscellaneous. We established a study design and specific objectives before commencing each literature research.

Instability

Methods

A systematic review was performed using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[180] The search was performed using the PubMed medical database in April 2020 (Fig. 1). The search terms used were [(Dislocation) OR (Instability) OR (Revision) OR (Reoperation) OR (Complication) AND (reverse shoulder arthroplasty) OR (reverse total shoulder) OR (reverse total shoulder arthroplasty)] with filters as follows: date range (1/1/2010 to 12/31/2019), species (human), and language (English). The search resulted in 761 total titles. Inclusion criteria were titles that specified primary or revision RSA. Exclusion criteria were duplicate titles, review articles, editorials, technique articles without reported patient outcomes, cadaveric studies, kinematic/finite element model/computer model analyses, case reports, survey studies, elastography/histologic studies, cost-benefit analyses, and instructional course lecture articles. After application of these criteria, 323 titles remained for abstract review. Articles that reported 2-year follow-up studies with clearly reported instability, reoperation, revision, or complication data were included. Articles with <15 patients, a minimum average follow-up of <24 months, and evaluated treatment of shoulder periprosthetic infection, blood transfusion rates, venous thromboembolism rates, RSA with concomitant tendon transfer, or RSA for tumor were excluded. This process eliminated 154 more articles, leaving 169 for full-text review. Articles with repeat data from publications prior to 2010 without further instability on long-term follow-up were also excluded in the full-text review. Definition of *instability/dislocation* was left to the discretion of each individual study. This final elimination stage resulted in 137 articles for inclusion in the analysis. Two authors (A.M.R. and S.S.S.) reviewed the articles and collected the data.

The rates of instability overall and according to (1) revision status (primary vs. revision arthroplasty vs. failed open reduction internal fixation [ORIF] proximal humerus fracture [PHF]), (2) publication date (2010-2016 vs. 2017-2020), (3) diagnosis, (4) center of rotation (CoR) (medialized vs. lateralized), and (5) prosthesis design were determined by pooled statistics. CoR and prosthesis design was defined according to Routman et al,[210] who stated that a glenosphere with a CoR of ≤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). Comparisons were also made to Zumstein et al.[293]

Statistical analysis was performed using SPSS (version 26; IBM Corp., Armonk, NY, USA). Univariate analysis was performed with the chi-square test, or with Fisher exact test when the expected count for at least 1 cell in the comparison was less than 5. The alpha level for statistical significance was set to 0.05.

Results

The majority of the studies were Level IV (96) and III (37), with only 3 Level II and 1 Level I evidence studies.* A total of 9306 shoulders were included in the analysis with a mean age of 72.1 years and 69.0% of female sex. The overall instability rate was 3.3% (308/9306 shoulders) at a mean follow-up of 3.2 years. When stratified by reoperations required and time to instability, 73.5% of dislocations required revision of components and 59.5% of shoulders with instability occurred within the first 90 days postoperatively (Table I). In total, there were 20 different implant systems encountered. Primary RSA instability rates were significantly lower at 2.5% vs. revision RSA (5.7%) or RSA for failed ORIF PHF rates (5.3%) ($P < .001$, $P = .01$, respectively) (Table II). The Grammont design (MG/MH) had a significantly higher instability rate vs. all other designs combined (4.0%, 1.3%; $P < .001$). Instability rates, especially modern non-Grammont designs, have significantly decreased compared with Zumstein et al[293] (Table III).

Humerus/glenoid fracture

Methods

A systematic review was performed using PRISMA guidelines.[180] The search was performed using the PubMed medical database in

* References 1, 4, 5, 7–9, 14, 20, 25, 26, 29–31, 35, 37, 40–42, 44, 46–49, 51–55, 58, 61, 62, 64, 66, 68, 72, 73, 75, 77, 78, 80, 81, 83–85, 87, 91–93, 98, 102, 103, 106–108, 110, 111, 113, 114, 116–119, 123, 125, 128, 131, 133, 136–138, 143, 146, 147, 149, 154, 155, 157, 160, 162–164, 169, 172–174, 178, 183, 185, 186, 188, 192, 194, 195, 197, 198, 200, 202, 204, 207–209, 213, 215, 217, 219, 220, 223–225, 228, 229, 231, 237, 245, 246, 250–255, 258–262, 264, 266, 267, 270, 273, 275, 277, 281, 287, 290, 292.

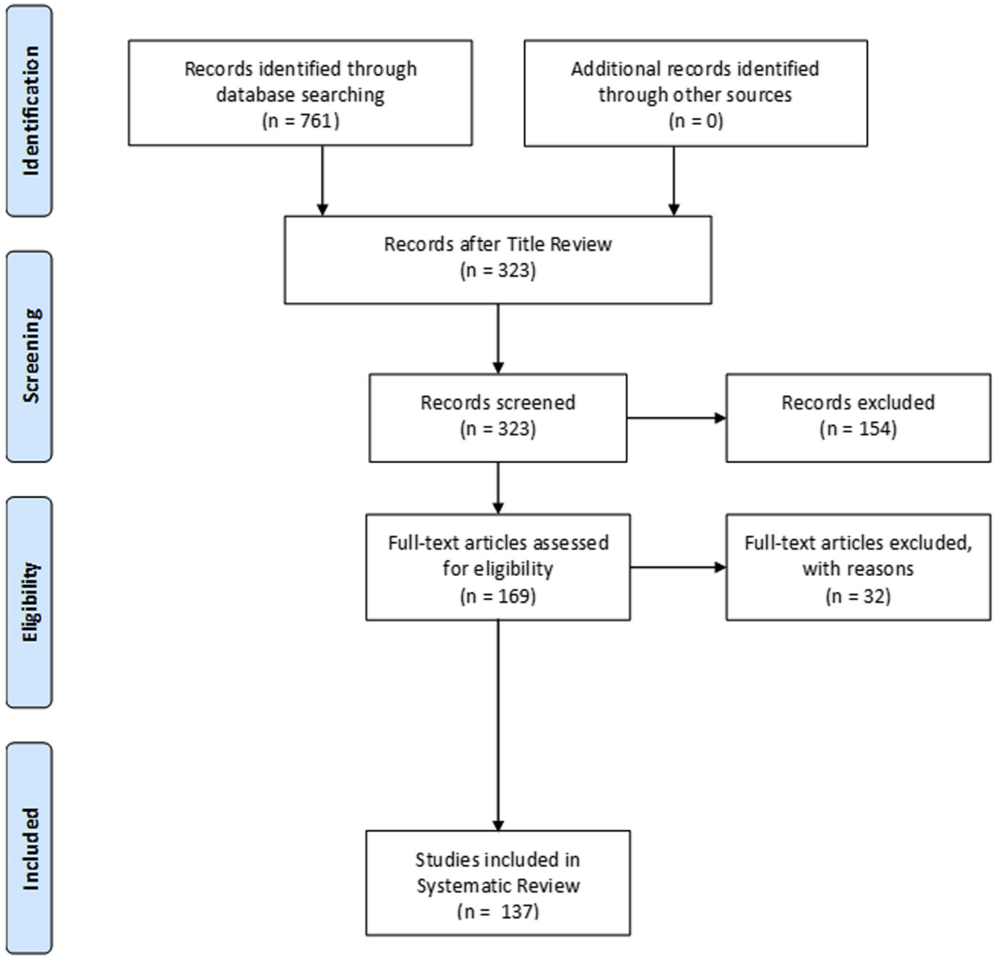

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram for instability.

July 2019 (Fig. 2). The search terms used were [(perioperative complication) OR (Complication) OR (Humerus fracture) OR (Glenoid Fracture) OR (Fracture) OR (Intraoperative fracture) OR (postoperative fracture) OR (revision) OR (reoperation)] AND [(reverse shoulder arthroplasty) OR (reverse total shoulder) OR (reverse total shoulder arthroplasty)] with filters as follows: date range (1/1/2010 to 5/1/2019), species (human), and language (English). The search resulted in 573 total titles. Inclusion criteria were titles that specified primary or revision RSA. Exclusion criteria were duplicate titles, review articles, editorials, technique articles without reported patient outcomes, cadaveric studies, kinematic/finite element model/computer model analyses, case reports, survey studies, elastography/histologic studies, cost-benefit analyses, and instructional course lecture articles. After application of these criteria, 304 titles remained for abstract review. Articles that reported 2-year follow-up studies with perioperative complication data, postoperative complication data, or clearly reported humerus fracture, glenoid fracture, intraoperative fracture, and postoperative fracture were lincluded. Articles with <25 patients, a minimum average follow-up of <24 months, and evaluated treatment of shoulder periprosthetic infection, blood transfusion rates, venous thromboembolism rates, RSA with concomitant tendon transfer, or RSA for tumor were excluded. This process eliminated 195 more articles, leaving 109 for full-text review. Definition of glenoid/humerus fracture was left to the discretion of each individual study. This final elimination stage resulted in 94 articles for inclusion in the analysis. Two authors (B.G. and S.S.S.) reviewed the articles and collected the data.

The rates of intraoperative humerus fracture (IHF), intraoperative glenoid fracture (IGF), postoperative humerus fracture (PostHF), postoperative glenoid fracture (PGF), overall and according to (1) diagnosis and (2) prosthesis design were determined by pooled statistics. Prosthesis design was defined according to Routman et al.[210] Comparisons were also made to Zumstein et al.[293]

Statistical analysis was performed using SPSS (version 26). Univariate analysis was performed with the chi-square test, or with Fisher exact test when the expected count for at least 1 cell in the comparison was less than 5. The alpha level for statistical significance was set to 0.05.

Results

The vast majority of the studies were Level IV and III evidence studies.[†] A total of 5539 shoulders were included in the analysis with a mean age of 71.3 years and 67.4% of female sex at a mean follow-up of 3.5 years. The overall rate was as follows: IHF = 1.8% (91/5539 shoulders), IGF = 0.3% (15/5539), PostHF = 1.2% (69/5539), and PGF = 0.1% (6/5539). In total, there were 20 different implant systems encountered. IGF and IHF rates using modern non-Grammont designs have significantly decreased compared with

† References 1, 4, 5, 14, 15, 17, 20, 24, 27, 28, 31, 34–37, 42, 44, 48, 54, 56, 61, 63, 68, 79, 80, 82, 87, 91–93, 98, 102, 108, 111–113, 116, 117, 119, 124, 125, 128, 131, 133, 138, 143, 147, 150, 154, 160, 164, 169–174, 176, 185, 186, 189, 191, 192, 194, 195, 198, 202–204, 211, 213, 215, 219, 223–225, 228, 234, 237, 241, 250, 252–254, 262, 265–267, 269, 275, 281, 282, 291, 292.

Table I
Instability rates overall, stratified by reoperations required and time to instability

	Studies included	Shoulders	Instability present	Rate, % (n/n)
Overall	137	9306	308	33 (308/9306)
Stratified by reoperations	127	6620	226	—
Revision of components	—	—	166	73.5 (166/226)
Closed reduction	—	—	41	18.1 (41/226)
Open reduction	—	—	1	0.4 (1/226)
Stratified by time to instability	32	1712	84	—
<90 d	—	—	50	59.5 (50/84)
>90 d	—	—	34	40.5 (34/84)

The majority of shoulders with instability occurred within the first 90 days postoperatively and were treated with revision of components as final treatment.

Table II
Rates of instability according to (1) publication date (2010-2016 vs. 2017-2020), (2) revision status (primary vs. revision arthroplasty vs. failed ORIF PHF), and (3) center of rotation

	Studies included	Shoulders	Instability present	Rate, %	*P* value
Year published					
2010-2016	68	4638	165	3.6	.18
2017-2020	69	4668	143	3.1	—
Primary vs. revision					
Primary RSA	86	6607	168	2.5	<.001 vs. revision; .01 vs. ORIF
Revision arthroplasty	37	1404	80	5.7	.81 vs. ORIF
Failed ORIF PHF	9	226	12	5.3	—
Center of rotation					
Medialized	88	4950	141	2.8	.15
Lateralized	22	1065	22	2.1	—

ORIF, open reduction internal fixation; *PHF*, proximal humerus fracture; *RSA*, reverse shoulder arthroplasty.
Primary RSA had significantly lower instability rates compared to both revision and failed ORIF PHF.

Table III
Rates of instability according to diagnosis and prosthesis design

	Studies included	Shoulders	Instability present	Rate, %	*P* value
Diagnosis					
Cuff tear arthropathy	15	905	21	2.3	.02 vs. PHF; <.001 vs. failed arthroplasty
PHF	36	1654	67	4.1	.03 vs. failed arthroplasty
Failed arthroplasty	29	1243	72	5.8	.62* vs. instability arthropathy
Instability arthropathy	4	80	3	3.8	>.99* vs. PHF; .44* vs. CTA
Prothesis design					
LG/MH	22	1021	20	2.0	.02 vs. MG/LH
MG/LH	16	1888	17	0.9	.02 vs. LG/MH
LG/LH	1	45	2	4.4	—
Subtotal	39	2954	39	1.3	<.001 vs. MG/MH
MG/MH	73	2932	116	4.0	—
Author					*P* value vs. Zumstein et al
Zumstein et al	21	782	37	4.7	—
Current study	137	9303	308	3.3	**.04**
Current study: subtotal of non-Grammont designs	39	2954	39	1.3	**<.001**

PHF, proximal humerus fracture; *LG*, lateralized glenoid; *MH*, medialized humerus; *MG*, medialized glenoid; *LH*, lateralized humerus; *CTA*, cuff tear arthropathy; *JSES*, *Journal of Shoulder and Elbow Surgery*.
The Grammont design (MG/MH) had a significantly higher instability rate vs. all other designs combined (4.0%, 1.3%; $P < .001$), instability rates, especially modern non-Grammont designs, have significantly decreased compared to Zumstein et al (*JSES*, 2011).
Bold indicates statistical significance ($P < .05$).
* Fisher exact test.

Zumstein et al (Table IV). Additionally, 62.7% of the postoperative fractures were attributed to traumatic events. When stratified by management, the majority of IHF and IGF were treated conservatively (Table V).

Acromial and scapular spine fractures

Methods

A systematic review was performed using PRISMA guidelines.[180] The search was performed using the PubMed and Web of Science databases in March 2020 (Fig. 3). The search terms used were [(reverse shoulder) OR (reverse total shoulder) OR (inverted shoulder)] with filters as follows: date range (1/1/2010- 12/31/2019), species (human), and language (English). The search resulted in 1863 total titles. Studies were included if they (1) reported clinical outcomes of RSA and (2) reported the incidence of acromial and scapular spine fractures. Duplicate titles, review articles, meta-analyses/systematic reviews, editorials, technique studies, or studies with fewer than 10 patients were excluded. Abstract review was then performed. Exclusion criteria were biomechanical studies, anatomic/cadaver studies, computer modeling studies, studies focusing on one outcome or complication other than AF, RSA for oncologic indications, isolated radiographic studies, and studies that excluded AF or SSF. Title and abstract review excluded 876 articles, leaving 340 articles for full-text review. In addition to the

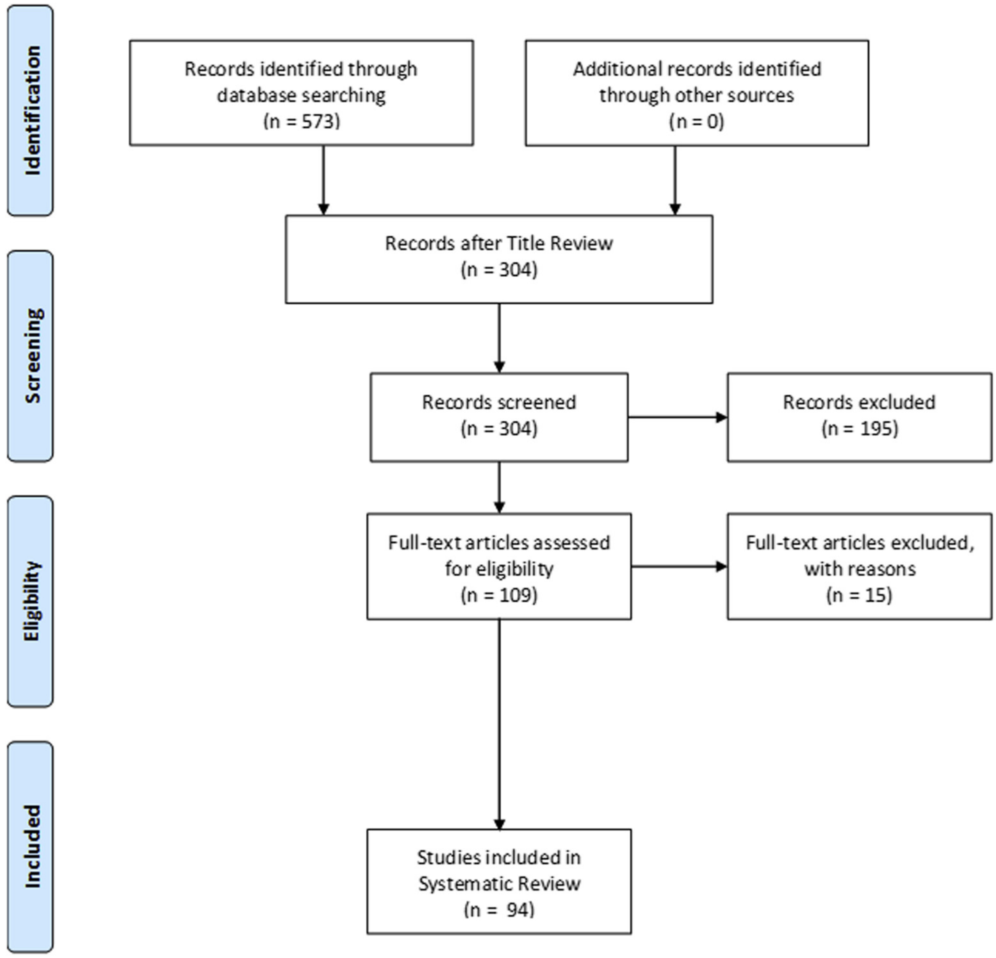

Figure 2 Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram for humerus/glenoid fracture.

Table IV
Fracture rates overall and compared to Zumstein et al

	Studies included	Shoulders	Fx present	Rate, %	*P* value
Current study					Vs. Zumstein et al
Intraop. humerus Fx	94	5539	97	1.8	.56
Intraop. glenoid Fx	94	5539	15	0.3	**.01***
Postop. humerus Fx	94	5539	69	1.2	.71
Postop. glenoid Fx	94	5539	6	0.1	—
Zumstein et al					Vs. current study
Intraop. humerus Fx	21	782	16	2.0	.56
Intraop. glenoid Fx	21	782	7	0.9	**.01***
Postop. humerus Fx	21	782	11	1.4	.71
Postop. glenoid Fx	21	782	NR	NR	—
Current study: subtotal of non-Grammont designs					Vs. Zumstein et al
Intraop. humerus Fx		1057	0	0.0	<.001
Intraop. glenoid Fx		1057	1	0.1	**.01***
Postop. humerus Fx		1057	23	2.2	.23
Postop. glenoid Fx		1057	1	0.1	—

Intraop, intraoperatively; *Postop.*, postoperatively; *Fx*, fracture; *NR*, not reported; *JSES*, *Journal of Shoulder and Elbow Surgery*.
Intraoperative glenoid fracture rates and intraoperative humerus fracture using modern non-Grammont designs have significantly decreased compared with Zumstein et al (*JSES*, 2011).
Bold indicates statistical significance ($P < .05$).

prior exclusion criteria, studies that did not mention AF and/or SSF were excluded; however, studies that had no acromial or scapular spine stress fractures in their population were included if they specifically mentioned a lack of these fractures. This final elimination stage excluded 220 articles, resulting in 120 articles included for final analysis. Two of 4 authors (S.D./J.K./A.S./S.S.S.) reviewed the articles and collected the data.

Acromial and scapular spine fracture rates overall and according to (1) revision status (primary vs. revision arthroplasty), (2) preoperative diagnoses, and (3) implant design were determined by

Table V
Number of fractures treated conservatively and fracture rates stratified by diagnosis and prosthesis design

	Number of Fx treated conservatively		Rate, % (n/n)	
Intraop. humerus Fx	52		53.6 (52/97)	
Intraop. glenoid Fx	10		66.7 (10/15)	
Postop. humerus Fx	25		36.2 (25/69)	
Postop. glenoid Fx	3		50 (3/6)	
Diagnosis	CTA	RCT	PHF	Failed arthroplasty
Shoulders	990	247	1443	1290
Intraop. humerus Fx	0.3 (3/990)	0 (0/247)	0.8 (11/1443)	5.5 (71/1290)*
Intraop. glenoid Fx	0.3 (3/990)	0 (0/247)	0.1 (2/1443)	0.2 (3/1290)
Postop. humerus Fx	0.2 (2/990)	0.8 (2/247)	0.5 (7/1443)	2.6 (33/1290)†
Postop. glenoid Fx	0.2 (2/990)	0 (0/247)	0 (0/1443)	0 (0/1290)
Prosthesis design	LG/MH	MG/LH	LG/LH	MG/MH
Shoulders	711	318	28	2839
Intraop. humerus Fx	0 (0/711)	0 (0/318)	0 (0/28)	1.6 (46/2839)‡
Intraop. glenoid Fx	0 (0/711)	0.3 (1/318)	0 (0/28)	0.1 (3/2839)
Postop. humerus Fx	2.1 (15/711)	2.5 (8/318)	0 (0/28)	1.1 (31/2839)§
Postop. glenoid Fx	0 (0/711)	0.3 (1/318)	0 (0/28)	0.2 (5/2839)

Intraop., intraoperatively; *Postop.*, postoperatively; *Fx*, fracture; *CTA*, cuff tear arthropathy; *RCT*, rotator cuff tear; *PHF*, proximal humerus fracture; *LG*, lateralized glenoid; *MH*, medialized humerus; *MG*, medialized glenoid; *LH*, lateralized humerus.
* $P < .001$ vs. CTA; $P < .001$ vs. RCT; $P < .001$ vs. PHF.
† $P < .001$ vs. CTA; $P = .09$ vs. RCT; $P < .001$ vs. PHF.
‡ $P = .001$ vs. LG/MH.
§ $P = .03$ vs. MG/LH; $P = .03$ vs. LG/MH.

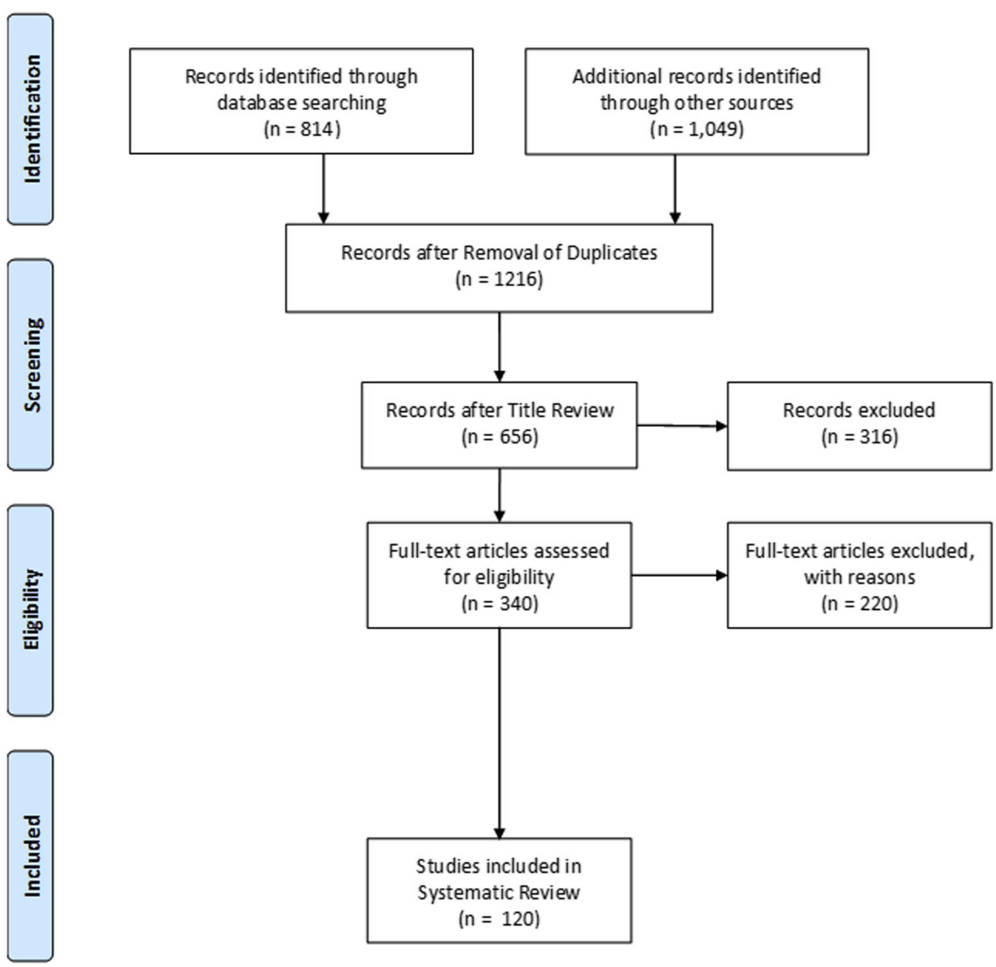

Figure 3 Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram for Acromial/Scapular Spine fractures

pooled statistics. Prosthesis design was defined according to Routman et al.[210] Comparisons were also made to Zumstein et al.[293]

Statistical analysis was performed using SPSS (version 26). Univariate analysis was performed with the chi-square test, or with Fisher exact test when the expected count for at least 1 cell in the comparison was less than 5. The alpha level for statistical significance was set to 0.05.

Results

The studies were mostly retrospective and provided Level III (38 studies) and Level IV evidence (78 studies), with 3 studies at Level II and 1 study providing Level I evidence.[‡] A total of 14,235 shoulders were included in the analysis with a mean age of 72.1 years and 58.7% of female sex. The overall rate of AF and/or SSF was 2.6% (371 of 14,235 RSAs) at a mean follow-up of 4.3 years. When stratified by type, AF were more commonly reported than SSF. A diagnosis of inflammatory arthritis had significantly higher rates of AF/SSF compared with CTA, RCT, and PHF. Despite improved surgeon awareness in diagnosing acromial/scapular fracture, there was no significant increase in fracture rates compared with Zumstein et al[293] (Table VI). The fracture rate was 2.5% after primary RSA and 2.7% after revision RSA ($P = .76$). There was no difference in acromial/scapular fracture rates for the Grammont design (MG/MH), at 2.5% (71/2817), vs. all other designs combined, at 2.5% (133/5420) (Table VII).

Problems and miscellaneous

Methods

A systematic review was performed using PRISMA guidelines.[180] The search was performed using the PubMed medical database in July 2019 (Fig. 4). The search terms used were [(Complication) OR (Revision) OR (Reoperation) OR (Algodystrophy) OR (CRPS) OR (Deltoid rupture) OR (Deltoid Injury) OR (Hematoma) OR (Seroma) OR (Heterotopic ossification) AND (reverse shoulder arthroplasty) OR (reverse total shoulder) OR (reverse total shoulder arthroplasty)] with filters as follows: date range (1/1/2010 to 05/31/2019), species (human), and language (English). The search resulted in 1008 total titles. Inclusion criteria were titles that specified primary or revision RSA. Exclusion criteria were duplicate titles, review articles, editorials, technique articles without reported patient outcomes, cadaveric studies, kinematic/finite-element model/computer model analyses, case reports, survey studies, elastography/histologic studies, cost-benefit analyses, and instructional course lecture articles. After application of these criteria, 209 titles remained for abstract review. Articles that reported 2-year follow-up studies clearly reported algodystrophy, complex regional pain syndrome (CRPS), deltoid rupture, deltoid injury, hematoma, seroma, heterotopic ossification (HO), reoperation, revision, or complication data were included. Articles with <15 patients, a minimum average follow-up of <24 months, and evaluated treatment of shoulder periprosthetic infection, blood transfusion rates, venous thromboembolism rates, RSA with concomitant tendon transfer, or RSA for tumor were excluded. This process eliminated 96 more articles, leaving 113 for full-text review. Definition of deltoid rupture, deltoid injury, hematoma, seroma, and/or HO was left to the discretion of each individual study. As there was rarely specific notation for algodystrophy/CRPS, any study with a description of pain as a postoperative problem/complication without an etiology was included; this was typically defined as "persistent pain" or "chronic pain." This final elimination stage resulted in 74 articles for inclusion in the analysis. Two authors (S.W.S. and S.S.S.) reviewed the articles and collected the data. Comparisons were made to Zumstein et al.[293]

Statistical analysis was performed using SPSS (version 26). Univariate analysis was performed with the chi-square test, or with Fisher exact test when the expected count for at least 1 cell in the comparison was less than 5. The alpha level for statistical significance was set to 0.05.

Results

The studies were mostly retrospective and provided Level III or IV evidence.[§] A total of 5529 shoulders were included in the analysis with a mean age of 71.5 years and 67.3% of female sex at a mean follow-up of 3.4 years. The overall rate was algodystrophy/CRPS = 0.4% (23/5529 shoulders), deltoid injury = 0.1% (5/5529), hematoma = 0.3% (15/5529), and HO = 0.8% (46/5529). Hematoma rates have significantly decreased compared to Zumstein et al (Table VIII). Additionally, 46.7% of all cases of hematoma were reported as requiring OR drainage.

Discussion

RSA has had wide adoption, with authors reporting good results in patients <55 years of age[195] and patients >65 years of age and OA with an intact rotator cuff.[239,244] Given the ubiquitous utility of RSA, it is not surprising to see variable complication rates being reported. However, as the indications continue to expand, the implants and prosthesis design improve as well. By limiting each search to publications after 2010 and by performing a systematic review for 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 only report revision rates and lack data on specific complication rates without revision.[144,179] By contrast, case series usually lack a large sample size that is necessary to make specific comparisons with increased power. The results of this study will serve 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 instability rate was 3.3% (308/9306) at a mean follow-up of 3.2 years. Instability rates, especially modern non-Grammont designs, have significantly decreased compared with Zumstein et al. The majority of dislocations required revision of components and occurred within the first 90 days postoperatively. Primary RSA instability rates were significantly lower vs. revision RSA or RSA for failed ORIF PHF. The Grammont design (MG/MH) had a significantly higher instability rate vs. all other designs combined. Finally, the MG/LH design had a significantly lower rate than the LG/MH. Once instability occurs, it is difficult to manage. Instability can be treated with closed reduction but may have limited success, ultimately leading to revision or poor outcome without further intervention.[204]

‡ References 2, 5, 12–15, 19, 21, 24, 28, 42–44, 46, 47, 50, 54, 58, 63, 65, 68, 71, 74, 77, 81, 84, 90–92, 95, 96, 99–102, 105, 106, 109–111, 113, 115, 118–120, 127, 129–131, 134, 135, 138, 139, 143, 145, 147, 149, 150, 152, 153, 155, 156, 161, 162, 166, 167, 169, 171, 173–175, 181–184, 186, 187, 189–191, 195, 200–202, 206, 213, 214, 218, 221, 224–226, 229–234, 238, 241, 243, 248, 249, 250, 252, 256, 259, 269–273, 276, 280, 285, 288–290.

§ References 3, 4, 6, 10, 15, 22, 23, 27, 32, 41, 42, 45, 48, 49, 51, 52, 55, 56, 58–60, 67, 74, 80, 81, 84, 88, 94, 98, 102, 106, 111, 113, 119, 122, 123, 127, 128, 142, 147, 151, 165, 169, 171, 173, 174, 177, 182, 187, 190, 192, 193, 195, 199, 202, 205, 206, 212, 216, 219, 222, 223, 231, 252, 257, 261, 262, 264, 269, 270, 274, 282, 283, 292.

Table VI
Acromial/scapular fractures rates overall and stratified by diagnosis

	Studies included	Shoulders	Acromial/scapular Fx	Rate, %	*P* value
Current study overall	120	14,235	371	2.6	.06
Zumstein et al	21	782	12	1.5	—
Current study: subtotal of non-Grammont designs	30	5420	133	2.5	.11 vs. Zumstein et al
Stratified by type	116	12,688	327	—	—
Acromial Fx	—	—	205	1.6 (205/12,688)	—
Scapular spine Fx	—	—	122	1.0 (122/12,688)	—
Diagnosis					
CTA	21	1407	36	2.6	**.04** vs. PHF; .91 vs. RCT; .002* vs. inflammatory
PHF	12	307	2	0.7	.053 vs. RCT
RCT	8	647	16	2.5	—
Inflammatory	5	153	12	7.8	**.001** vs. RCT; <**.001*** vs. PHF

Fx, Fracture; *CTA*, cuff tear arthropathy; *PHF*, proximal humerus fracture; *RCT*, massive rotator cuff tear; *JSES*, *Journal of Shoulder and Elbow Surgery*.
A diagnosis of Inflammatory arthritis had significantly higher rates compared to CTA, RCT, and PHF. Despite improved surgeon awareness in diagnosing Acromial/Scapular Fx, there was no significant increase in rates compared to Zumstein et al (*JSES*, 2011).
* Fisher exact test.

Table VII
Acromial/scapular fracture rates according to (1) revision status (primary vs. revision) and (2) prosthesis design

	Studies included	Shoulders	Acromial/scapular fractures	Rate, %	*P* value
Primary vs. revision					
Primary RSA	82	7244	181	2.5	.76
Revision RSA	21	707	19	2.7	—
Prothesis design					
LG/MH	16	2534	72	2.8	.13 vs. MG/LH; .18* vs. LG/LH; .47 vs. MG/MH
MG/LH	13	2746	60	2.2	.37* vs. LG/LH; .41 vs. MG/MH
LG/LH	1	140	1	0.7	.26* vs. MG/MH
Subtotal	—	5420	133	2.5	—
MG/MH	45	2817	71	2.5	—

RSA, reverse shoulder arthroplasty; *LG*, lateralized glenoid; *MH*, medialized humerus; *MG*, medialized glenoid; *LH*, lateralized humerus.
There was no difference in acromial/scapular fractures rates for the Grammont design (MG/MH) at 2.5% (71/2817) vs. all other designs combined at 2.5% (133/5420).
* Fisher exact test.

However, revision may still lead to recurrent instability.[40,137] Furthermore, it is important to note that the definition of instability was left to each study; the incidence of more subtle forms of instability has been shown to have negative effects on ASES scores compared with patients without signs of instability.[246]

There are multiple variables that may play a role in the etiology of instability: male gender, prior open operations, preoperative diagnoses of proximal humeral or tuberosity nonunion,[40] superior baseplate inclination,[246] and intraoperative resection of tuberosities.[192,204] Furthermore, achieving anatomic soft tissue tensioning, specifically of the deltoid, plays a role in the overall stability of the prosthesis. It has been suggested that obesity may prevent the surgeon from accurately evaluating soft tissue tensioning during surgery, leading to subsequent instability.[38] Additionally although some reports have found absence of subscapularis repair being significantly associated with prosthetic instability,[40] others found no difference between repair vs. no repair,[261] and using a lateralized RSA subscapularis repair may not be necessary.[207]

On the basis of this study, the global rate for IHF was 1.8% (91/5539 shoulders); IGF, 0.3% (15/5539); PostHF, 1.2% (69/5539); and PGF, 0.1% (6/5539), with the majority of intraoperative fractures, both glenoid and humerus, treated with no additional intervention. IGF and IHF rates using modern non-Grammont designs, have significantly decreased compared to Zumstein et al. Numerous factors play a role in the incidence of fracture. Risk of IHF has been shown to be increased by female sex, history of instability, prior hemiarthroplasty, and revision RSA cases.[265] To avoid IHF during revision surgery, lateral humeral split has been suggested as the least aggressive means of extracting the humeral implant. Glenoid fractures during surgery are rare, typically related to the reaming or fixation process; IGFs may occur in PHF cases as a result of over-reaming because there is less sclerotic bone in the typically unaffected glenoid.[211] Although many glenoid fractures can be addressed by fixation or redirection of the baseplate, in the case of substantial glenoid fractures it may be necessary to implement a 2-stage bone grafting and reimplantation process. Patients treated with RSA combined with allograft-prosthetic composite[48] and cement-within-cement fixation of the humeral component in revision RSA have both been discussed as at risk for PostHF.[266] PostHF are most commonly associated with traumatic events, can have significant negative impacts on clinical outcomes, and has been shown to be more likely to occur in older patients, females, and those operated on via a transdeltoid approach.[11]

An explanation for some recent studies reporting fracture is the “the learning curve” of a new implant.[14] Many intraoperative fractures occurred early on with the use of a short-stem prosthesis[14] as well as stemless implants.[150] Because of the technically demanding nature of stemless implants, there is a high susceptibility to fracture both intraoperatively and postoperatively, especially fracture of the humeral metaphysis due to excessive bone impaction in soft bone.[150]

On the basis of this study, the overall rate of AF and/or SSF was 2.6% (371 of 14,235 RSAs [1.6% for AF and 1.0% for SSF]). This is similar to the recent King et al[132] study (2.8%); however, our study is inclusive of 2 more years of data with approximately 5000 more shoulders included. A diagnosis of inflammatory arthritis had significantly higher rates of AF/SSF compared with CTA, RCT, and

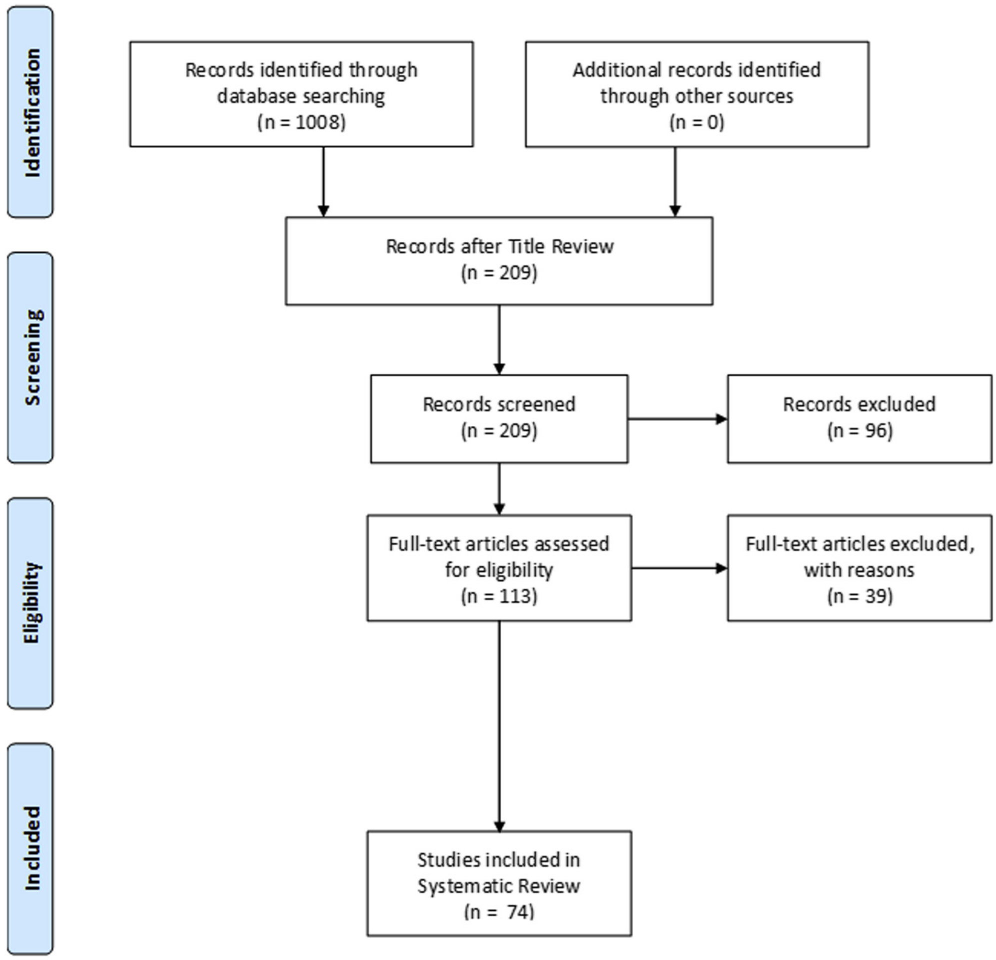

Figure 4 Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram for problems/miscellaneous.

Table VIII
Pooled estimates of CRPS, deltoid injury, hematoma, and heterotopic ossification following RSA

	Studies included	Shoulders	Incidence	Current study rate, % (n/n)	Zumstein et al rate, % (n/n)	*P* value current study vs. Zumstein et al
CRPS	74	5529	23	0.4 (23/5529)	0.5 (4/782)	.77*
Deltoid injury	74	5529	5	0.1 (5/5529)	—	—
Hematoma	74	5529	15	0.3 (15/5529)	2.6 (20/782)	**<.001***
Heterotopic ossification	74	5529	46	0.8 (46/5529)	0.8 (6/782)	.86

CRPS, complex regional pain syndrome; *RSA*, reverse shoulder arthroplasty; *JSES*, *Journal of Shoulder and Elbow Surgery*.
Hematoma rates have significantly decreased compared with Zumstein et al (*JSES*, 2011).
* Fisher exact test.

PHF. Despite improved surgeon awareness (including expansion of previous definition[168] to include persistent pain without magnetic resonance imaging or bone scan changes and improved diagnostic imaging) for diagnosing acromial/scapular fracture, there was no significant increase in rates compared with Zumstein et al. Some authors have theorized that acromion fractures are caused by excessive tensioning of the deltoid with RSA that causes significant inferior stress on the acromion[70,148] possibly influenced by the anatomic position of the acromion.[227] Excessive lowering of the humerus can lead to arm lengthening and thus increased resting tension of the deltoid on the tip of the acromion.[278] Also, excessive medialization may create a lower deltoid wrapping angle, leading to a more vertical line of pull from the deltoid producing an increased bending moment arm applied to the acromion, further placing the acromion at risk for fracture. In these cases, the greater tuberosity cannot act as a pulley of reflection for the deltoid anymore.[278]

In our study, the LG/MH design had the highest reported incidence of AF/SSF at 2.8%. This compares to 2.5% and 2.2% in the MG/MH and MG/LH designs, respectively. All comparisons were not statistically significant. A finite element study by Wong et al[284] showed that glenosphere lateralization significantly increased acromial stress by 17%. Other studies have shown a decreased deltoid moment arm with glenosphere lateralization, which may also affect acromial stresses.[86,97] As the moment arm decreases, there is increased force required by the deltoid to abduct the arm in elevation, thus increasing stress on the acromion.

AF and SSF can lead to worse outcomes after RSA[105,148,168,242,249,268]; however, these patients typically still have better functional scores compared with preoperative values.[105,148,249] Some authors advocate operative intervention for displaced AF affecting a large portion of the deltoid; however, operative intervention has not been shown to improve overall outcomes.[168] No consensus on the recommended treatment of these fractures has been reached.[105,168,268] Risk factors for AF and SSF reported in clinical studies are osteoporosis, a smaller lateral offset of the greater tuberosity, and increased arm lengthening.[196,278] One theory about how to prevent SSF is to avoid putting screws through the junction of the scapular spine and the scapular body, which may act as a stress riser. One study showed a significantly lower rate of SSF when no superior screws were used (0% of 112 RSAs) compared with when screws were used above the metaglene central cage (4.4% of 209 RSAs).[130] Another study suggests that coracoacromial ligament transection during surgical exposure for RSA alters strain patterns along acromion and scapular spine, leading to an accumulation of microtrauma, which may lead to stress fracture.[247]

The term *problem* refers to events perceived as adverse but unlikely to affect the final outcome, that is, algodystrophy/CRPS, hematoma, and heterotopic ossification.[16] On the basis of this study, the overall rate for algodystrophy/CRPS is 0.4% (23/5529 shoulders); deltoid injury, 0.1% (5/5529); hematoma, 0.3% (15/5529); and HO, 0.8% (46/5529). Hematoma rates have significantly decreased compared with Zumstein et al. CRPS may perhaps be underreported in the literature; many studies report persistent pain,[59,67,182] chronic pain,[81] or greater than moderate pain.[4] Thus, in an attempt to accurately gauge the rates of CRPS, we included any description of pain listed as a postoperative problem or complication without an etiology. However, there is typically a delayed diagnosis following orthopedic surgery with a mean time delay of 3.9 years before diagnosis of CRPS. A lack of attention to more subtle signs of autonomic dysfunction may be an important contributing factor for a missing CRPS diagnosis.[158] Deltoid injury may be attributed to arm lengthening[140] whereas massive rotator cuff tears with retraction and patients with prior open rotator cuff surgery have been shown to be risk factors for postoperative deltoid rupture.[279] Patients with preoperative deltoid impairment or postoperative rupture can still obtain good range of motion and pain scores.[141,279] A wide range of rates for postoperative hematoma have been reported in the literature, which can be attributed to the lack of reporting in situations in which intervention was not required. Although hematomas are unlikely to affect the final outcome, they may pose an increased risk for the development of infection. Most cases of HO are benign, requiring neither nonsteroidal anti-inflammatory drugs, prophylaxis, or treatment. Only grade 2 HO is clinically relevant, with a negative effect on the function of the shoulder during its development.[257] Factors reported to increase the risk of HO include surgical approach, the extent of operative release of soft tissues such as release of the triceps in the superolateral approach,[257] procedures where bone graft is used,[80] and RSA with cerclage for complex proximal humerus fracture with extended diaphyseal involvement.[81]

Limitations of this study are similar to 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, complication rates in this study are only from published data predominantly out of high-volume centers; this may not capture the rate or distribution of complications in the general population, “many of whom perform only a few of these procedures each year.”[236] High-volume centers have been reported to have better perioperative quality metrics[235] and maximized outcomes after RSA, likely related to surgical experience.[69] Thus, complex procedures, such as RSA, have been advised to be performed at high-volume destinations, or it has been encouraged that lower-volume institutions strategize to function as a higher-volume center.[69] Also, a statistician reviewed the collected data and concluded that a multivariate analysis of the results was not possible because of the heterogeneity of the reported outcomes, the lack of reporting of standard deviation in most studies, and the lack of control groups in the included studies. 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 a large sample size necessary to make comparisons with clinical value.

Conclusion

Focused systematic reviews of recent literature with a large volume of shoulders demonstrate that using modern non-Grammont prosthesis designs, complications including instability, intraoperative humerus and glenoid fractures, and hematoma are significantly reduced compared with previous studies. In addition, modern RSA designs carry an AF/SSF rate of 2.5%. As the indications continue to expand for RSA, it is imperative to accurately track the rate and types of complications in order to justify its cost and increased indications.

Disclaimer

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