Decreased Reoperations and Improved Outcomes With Reverse Total Shoulder Arthroplasty in Comparison to Hemiarthroplasty for Geriatric Proximal Humerus Fractures: A Systematic Review and Meta-Analysis

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Objectives: We sought to compare range of motion, clinical outcome scores, and complications after reverse total shoulder arthroplasty (RSA) and hemiarthroplasty (HA) in geriatric patients with acute proximal humerus fractures.

Data Sources: We searched MEDLINE (1946–2017), EMBASE (1947–2017), the Cochrane Central Register of Controlled Trials (1898–2017) and ClinicalTrials.gov in October 2017. No limits were used in the database search. We also manually reviewed reference lists of included studies. We did not restrict studies based on language.

Study Selection: We included all randomized controlled trials and cohort studies in which the study population had a mean age of 65 years or older, received RSA or HA to treat an acute proximal humerus fracture, and had a minimum follow-up of 6 months.

Data Extraction: Two independent reviewers used a standardized data collection form to extract relevant information from included studies. Discrepancies were resolved by a consensus or a third party if consensus could not be reached. Study authors were contacted for missing or incomplete data.

Data Synthesis: Using a random effects model, we calculated mean differences (MD) and standardized mean differences (SMD) for continuous outcomes; we calculated relative risk for dichotomous outcomes.

Results: Fifteen studies were included in the meta-analysis, including 421 patients treated with RSA and 492 treated with HA for a total of 913 patients. Compared with HA, the RSA group had significantly improved pain scores (SMD = 0.74, $P < 0.001$), outcome scores (SMD = 0.63, $P < 0.001$), and forward flexion (MD = 24.3 degrees, $P < 0.001$). Compared with RSA, the HA group had a significantly increased risk of reoperation (relative risk = 2.8, $P = 0.02$). There were no differences between the groups with regard to external rotation ($P = 0.31$) or deep infection ($P = 0.90$).

Conclusions: Aggregating available research suggests that RSA results in improved range of motion, clinical outcome scores, and rates of all-cause reoperation with no difference in infection rates. Using RSA for the treatment of acute proximal humerus fractures in the elderly population may result in improved short- and medium-term outcomes compared with HA. Future work should evaluate long-term outcomes to see if the benefits of RSA persist.

Key Words: reverse total shoulder arthroplasty, hemiarthroplasty, proximal humerus fracture, clinical outcomes, complications

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

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BACKGROUND

Proximal humerus fractures are common fragility fractures that account for 10% of all fractures in patients older than 65 years of age in the United States.[1–3] Treatment of these fractures is highly variable, with overall surgical treatment rates of approximately 15%, despite a lack of consensus among surgeons regarding indications for surgery.[3,4] Among surgical candidates, hemiarthroplasty (HA) has been the historical treatment of choice in elderly patients with poor bone quality and complex fracture patterns not amenable to internal fixation.[5–7] However, inconsistent results, poor functional outcomes,[6–9] and long-term complications[10] have been reported after HA. More recently, reverse total shoulder arthroplasty (RSA) has been introduced as an alternative treatment option,[11–16] and its use has increased dramatically within the United States.[17–19] Purported benefits of RSA compared with HA include less dependence on tuberosity healing for improved active overhead function, decreased pain, and lower incidence of revision surgery.

High-quality comparative studies examining outcomes between RSA and HA are relatively scarce; indeed, only 1 randomized controlled trial has been published on the topic.[14] Previous systematic reviews and meta-analyses have come to mixed conclusions, but in aggregate have suggested benefits to RSA.[20–24] However, these previous studies have been limited by

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the small numbers of patients included. A recent outpouring of new literature comparing RSA and HA for proximal humerus fractures,[11,12,25–28] as well as the recognition of studies that had not been included in previous analyses including non-English studies,[29,30] greatly expands the available data and warrants an updated systematic review and meta-analysis, with an expanded focus on reoperation rates and postoperative complications. Our objective was to complete a comprehensive meta-analysis and systematic review comparing clinical outcomes and postoperative complications between RSA and HA for the treatment of proximal humerus fractures in geriatric patients.

METHODS

Review Protocol

We wrote an a priori protocol outlining our planned approach. We followed the methods outlined in the Cochrane Handbook[31] and the PRISMA Statement[32] to create our protocol.

Study Eligibility Criteria

Our inclusion criteria were as follows: study designs including randomized control trials, retrospective and prospective cohort studies, a comparison of RSA to HA for the treatment of proximal humerus fractures in patients with a mean age greater than 65years, at least 6-month follow-up for clinical outcomes and complications, and reporting of at least one of our prespecified outcomes.

Outcome Measures

Range of motion included forward flexion, abduction, and external rotation in degrees.

Clinical scores includedg the Constant score,[33] American Shoulder and Elbow Surgeons (ASES) score,[34] Oxford Shoulder Score,[35] Disabilities of the Shoulder and Hand (DASH) score,[36] Penn Shoulder Score,[37] University of California Los Angeles (UCLA) Shoulder Score,[38] the Simple Shoulder Test,[39] and the Visual Analog Scale (VAS).[40] Postoperative complications included all-cause reoperation rate, aseptic revision rate, deep infection rate, status of tuberosity healing, neurovascular injury, and instability, which was defined as any dislocation event.

Search Methods

Databases, Search Terms, Limits

We searched the following electronic databases in October 2017: MEDLINE (1946–2017), EMBASE (1947–2017), and the Cochrane Library (CENTRAL) (1898–2017) and NIH ClinicalTrials.gov (see **Figure, Supplemental Digital Content 1**, http://links.lww.com/JOT/A488). Our themes for searching the databases were "Shoulder Arthroplasty" and "Proximal Humerus Fracture." We did not restrict studies based on language. We manually reviewed references of relevant articles including all systematic reviews and meta-analyses conducted in the past 10 years.

Study Selection

After removing duplicates (N.H.C.), 2 reviewers (D.C.A. and M.T.T.) screened by title and abstract. Articles that initially met the criteria were then further evaluated by a full-text review. Non-English studies were translated by fluent speakers in conjunction with study authors.

Data Collection

We used a standardized data collection form to extract relevant data from included studies by 2 reviewers. Discrepancies were resolved by a consensus or a third party if consensus could not be reached.

Assessment of Methodological Quality

We used the Cochrane Risk of Bias (ROB) tool[41] and the Newcastle Ottawa Scale (NOS)[42] to determine the methodological quality of included randomized control trials and cohort studies, respectively.

Analysis

Measure of Treatment Effect

We analyzed range of motion and the individual clinical outcome scores using mean differences (MDs). To combine disparate outcome measures, we calculated the standardized mean difference between the groups. A predetermined hierarchy, designed to minimize the number of different clinical outcome scores, was developed a priori as follows: Constant, ASES, DASH/QDASH, and Oxford Shoulder Score. The order of the hierarchy was determined by the frequency of reported scores in the included studies (highest to lowest) and was used whenever studies reported more than 1 score. Pain measurements, including the visual analog pain scale and the pain subscores of the Constant or ASES clinical scores, were combined and compared using a standardized mean difference. We used risk ratios to analyze dichotomous variables. All-cause reoperation was defined as any return to the operating room to address the original implant. We restricted our postoperative complication analysis to include only those studies in which the intervention group (RSA) had at least 75% of the follow-up time of the control group (HA) or vice versa. We calculated 95% confidence intervals for all comparisons and considered $P < 0.05$ to be statistically significant.

Dealing with Missing Data

When data were missing, statistical methods outlined in the Cochrane handbook were used when possible.[43] The methodology found in the Cochrane Handbook section 7.7.3 includes calculating a standard deviation from the P value of a t test, an interquartile range, or a standard error.[43] When other methods were not possible for determining a missing standard deviation, we used an average standard deviation from the other included studies as outlined in the Cochrane Handbook section 16.1.3.1.[43] When data remained incomplete, we contacted authors requesting relevant information[16,27,30,43,44] and received replies from half.[16,44]

Data Synthesis

We used RevMan 5.3[45] to analyze and summarize the findings of studies using the random effects model. Given the methodological differences of the studies examined, we

elected to use the random effects model because of its more conservative nature. If there were more than 1 shoulder score reported by a study, we used the previously described hierarchy to determine which score to include in the summary estimate. Qualitative analysis was used for studies not able to be included in our meta-analysis.[26]

Sensitivity Analyses

We used the results from the NOS and Cochrane ROBTool to determine the quality of included studies. We performed a sensitivity analysis, that was defined a priori, to analyze the summary estimates of range of motion and clinical outcome scores in low-quality studies (NOS score <6, ROB majority high risk) compared with high-quality cohort studies (NOS score ≥ 6, ROB majority low risk).

RESULTS

Description of Studies

Results of Search

We identified 3032 unique references by means of our search strategy. After screening titles and abstracts, we retrieved 57 articles for full-text review. After full-text review, 17 studies met our inclusion criteria as outlined in Figure 1.

Included Studies

There were 17 studies which met our inclusion criteria, 1 randomized controlled trial and 16 comparative cohort studies (Table 1). We included 15 studies containing 913 patients in the meta-analysis, including 421 patients who underwent RSA and 492 who underwent HA. Studies by Brorson et al[26] and Dillon et al[46] were only able to be included as part of the systematic review. In total, our systematic review included 1163 RSA patients and 7837 HA patients. Patients in the RSA group were older (77.2 years) compared with those in the HA group (71.31 years). Both groups were composed of a female majority, with more women represented in the RSA group (82.8%) compared with the HA group (76.1%). Average follow-up duration was higher in the HA group (36.3 months) compared with the RSA group (23.3 months). Overall range of follow-up was 6–108 months.

Methodological Quality of Included Studies

The 1 randomized controlled trial that was included had a low ROB according to the Cochrane ROB tool.[41] The remainder of the studies included were cohort studies, which overall had a low to moderate ROB based on the NOS. There were also variable rates of follow-up between studies and within study groups, introducing bias. The full analysis of methodological quality for all studies is available in **Supplemental Digital Content 2** (see **Figure**, http://links.lww.com/JOT/A489).

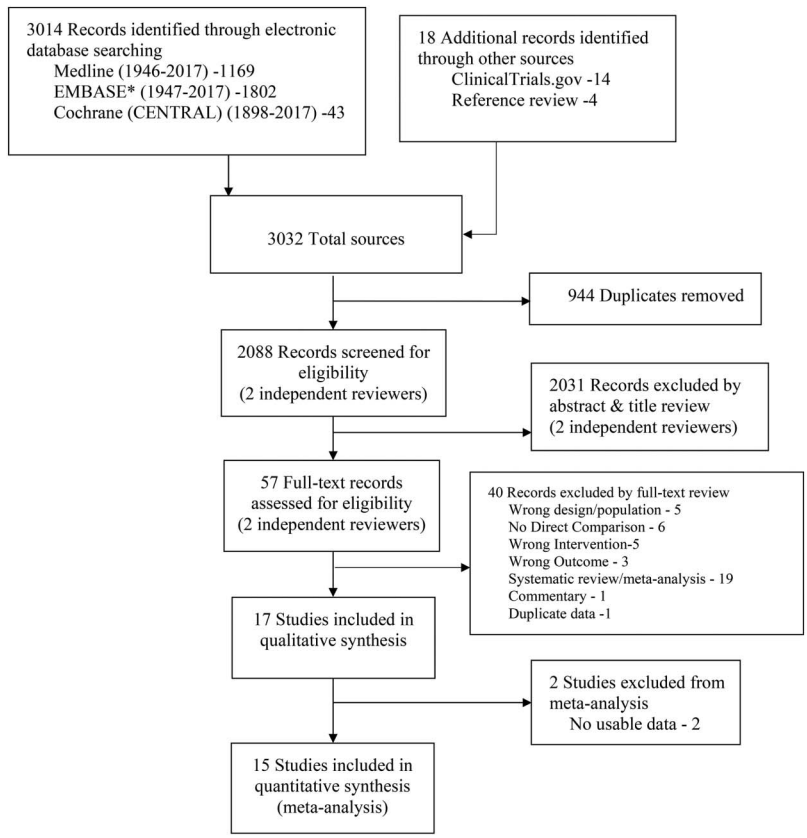

FIGURE 1. Study Selection Flow Diagram. *EMBASE: Excerpta Medica Database

TABLE 1. Characteristics of Studies Comparing Reverse Shoulder Arthroplasty With Hemiarthroplasty

Author, Year	Country	Subjects (n)	Age, y (mean)	Sex (% Female)	Type of Humerus Fracture
Randomized control trial	RSA: HA	RSA: HA	RSA: HA		
Sebastia-Forcada et al, 2014[14]	Spain	31:30	74.7:73.3	87.1:83.3	3- and 4-part fracture, fracture-dislocations, head split
Cohort studies					
Aldegheri et al, 2008[29]	Italy	17:32	78	83.3	3- and 4-part fractures
Baudi et al, 2014[15]	Italy	25:28	77:70	87	3- and 4-part displaced fractures, head fracture dislocation
Bonneville et al, 2016[11]	France	41:57	78:67	90:68	4-part fracture
Boyer et al, 2017[28]	France	65:69	78:68	NR	3- and 4-part fractures
Brorson et al, 2017[26]	Denmark, Sweden, Norway	565:6112	77:72	80:80	Acute proximal fractures
Chalmers et al, 2014[48]	USA	9:9	77:72	78:75	3- and 4-part fractures, head split
Cuff and Pupello, 2013[16]	USA	24:23	74	NR	3- and 4-part fractures, head split
Dillon et al, 2015[46]	USA	72:961	75:68	68:62	Proximal fracture
Fu, 2013[30]	China	11:12	82.2:68.5	73:58	3- and 4-part acute proximal fractures
Gallinet et al, 2008[49]	France	16:17	74:74	81:88	3- and 4-part fractures
Garrigues et al, 2012[44]	USA	10:9	80.5:69.3	NR	3- and 4-part fractures, head split, fracture-dislocation
Hanssens et al, 2005[50]	Belgium	6:8	81:76	NR	3- and 4-part fractures
Repetto et al, 2017[25]	Italy	27:24	71.2:67.5	NR	3- and 4-part fractures, head split, fracture-dislocation
Solomon et al, 2016[27]	USA	16:8	77:77	81:89	3- and 4-part fractures
van der Merwe et al, 2017[12]	New Zealand	218:427	78.2:71.6	89.9:77.3	Acute proximal fractures
Young et al, 2010[51]	New Zealand	10:10	77.2:75.5	100:80	3- and 4-part fractures

Author, Year	RSA Implant	HA Implant	Mean Follow-up (mo)	Range Follow-up (mo)	Completeness of Follow-up (%)
Randomized control trial			RSA: HA		RSA: HA
Sebastia-Forcada et al, 2014[14]	SMR	SMR	29.4:27.7	24–49	100:96.8
Cohort studies					
Aldegheri et al, 2008[29]	NR	NR	15:19	6–42	100:100
Baudi et al, 2014[15]	Zimmer, SMR, Delta	Aequalis, Zimmer, SMR	27	12–64	85
Bonneville et al, 2016[11]	NR	NR	39	24–63	58.8:60
Boyer et al, 2017[28]	Locked uncemented stem	Locked uncemented stem	NR	NR	NR
Brorson et al, 2017[26]	NR	NR	NR	12–108	NR
Chalmers et al, 2014[48]	Zimmer	Zimmer	14.4:58.8	8–72	NR
Cuff and Pupello, 2013[16]	DJO	Aequalis, DJO	30	24–48	88.9:88.5
Dillon et al, 2015[46]	NR	NR	28.2:46	NR	96:91
Fu, 2013[30]	Delta III, Aequalis	Aequalis, global FX	43.2	15.6–96	45:100
Gallinet et al, 2008[49]	Delta III	Aequalis	12.4:16.5	6–55	81:84.2
Garrigues et al, 2012[44]	Delta III	Global FX, Aequalis	43.2	15.6–96	91:75
Hanssens et al, 2005[50]	Delta III	Global	20	NR	75:89
Repetto et al, 2017[25]	SMR	NEER II, SMR	41.7:42.2	NR	100:100
Solomon et al, 2016[27]	Aequalis	Bigliani/Flatow	43	18–73	100:100
van der Merwe et al, 2017[12]	NR	NR	NR	NR	52:36.4
Young et al, 2010[51]	NR	SMR	22:44	16–56	100:100

DJO, DJO global; n, number; NR, not reported; SMR, Systema Multiplana Randelli.

Effects of Interventions

Range of Motion

Among the 12 studies that reported forward flexion, RSA demonstrated an improvement in forward flexion of 24.3 degrees compared with the HA group (MD 24.3 degrees, 95% CI 15.6 degrees–33.0 degrees, $P < 0.0001$; see **Figure, Supplemental Digital Content 3**, http://links.lww.com/JOT/A490; and **Table Supplemental Digital Content 4**, http://links.lww.com/JOT/A491). The RSA group also showed an improvement in abduction compared with the HA group in the 5 studies that reported this outcome (MD 26.4 degrees, 95% CI 13.3 degrees–39.5 degrees, $P < 0.0001$).

Among the 12 studies that reported external rotation, there was no difference between the 2 groups (MD −1.6, 95% CI −4.6 degrees to 1.5 degrees, $P = 0.31$; see **Figure, Supplemental Digital Content 5**, http://links.lww.com/JOT/A492).

Functional Outcome Scores

The RSA group showed greater improvement in functional outcome scores compared with the HA group among the 14 studies that reported a clinical outcome score [standardized mean differences (SMD) 0.63, 95% CI 0.39–0.86, $P < 0.0001$; Figure 2, see **Table, Supplemental Digital Content 6**, http://links.lww.com/JOT/A493]. We also examined average differences between RSA and HA in the 3 most common outcome scores reported in the included studies (7 studies reported Constant scores, 6 reported ASES scores, and 5 reported DASH scores). RSA showed significant improvement in Constant scores (MD 12.7 points, 95% CI 8.9–16.5; $P < 0.0001$) and ASES scores (MD 16.1 points, 95% CI 9.5–22.7, $P < 0.0001$). However, we found no difference in DASH scores between RSA and HA (MD 2.6 points, 95% CI −2.7–8.0, $P = 0.33$). We further examined visual analog scale scores in combination with pain subscores of clinical outcome scores when they were reported in 9 studies. Among these studies, the results favored RSA (SMD 0.74, 95% CI 0.4–1.1, $P < 0.0001$, see **Figure, Supplemental Digital Content 7**, http://links.lww.com/JOT/A494).

Postoperative Complications

Eight studies reported all-cause reoperation. Nine studies reported on aseptic failure and deep infection (Table 2). In the meta-analysis, the HA group had a significantly higher risk of all-cause reoperation [relative risk (RR) 2.8, 95% CI 1.2–6.3, $P = 0.02$; Fig. 3] and aseptic failure (RR 4.0, 95% CI 1.5–11.1, $P = 0.008$). There was no significant difference in the rate of deep infection between the 2 groups (RR 0.9, 95% CI 0.2–3.7, $P = 0.9$; see **Figure, Supplemental Digital Content 8**, http://links.lww.com/JOT/A495). Nine studies reported results of tuberosity healing. Among those studies, there was no difference in the risk of tuberosity nonunion or malunion (RR 1.51, 95% CI 0.98–2.34, $P = 0.06$). Tuberosities were reported to be repaired partially or completely in 11 of 12 studies that specifically described their surgical technique, making subgroup analysis between repair versus excision impossible. Instability was a rare outcome precluding formal meta-analysis; however, weighted dislocation rates were higher in the RSA group (0.68 events/100 patient years) compared with the HA group (0.29 events/100 patient years; Table 2). Postoperative neurologic deficits were very rare, with only 10 total events reported (7 HA, 3 RSA). There were no postoperative arterial injuries reported in either group.

There were 3 large-scale database studies that reported on complications in ways that could not be analyzed by formal forest plots.[12,26,46] Brorson et al (2017) reported 5-year survival implant rates of 0.96 for both RSA and HA for proximal humerus fracture, with no significant difference between the groups. Van der Merwe et al (2017) reported on revision rate per 100 component-years for both the RSA and HA group, with no significant differences in the revision rates between the groups (0.58 for RSA vs. 1.16 for HA, $P = 0.137$). These results are consistent with Dillon et al[46] who observed generally similar revision rate in the HA (0.82 revisions/100 patient years) and RSA groups (0.59

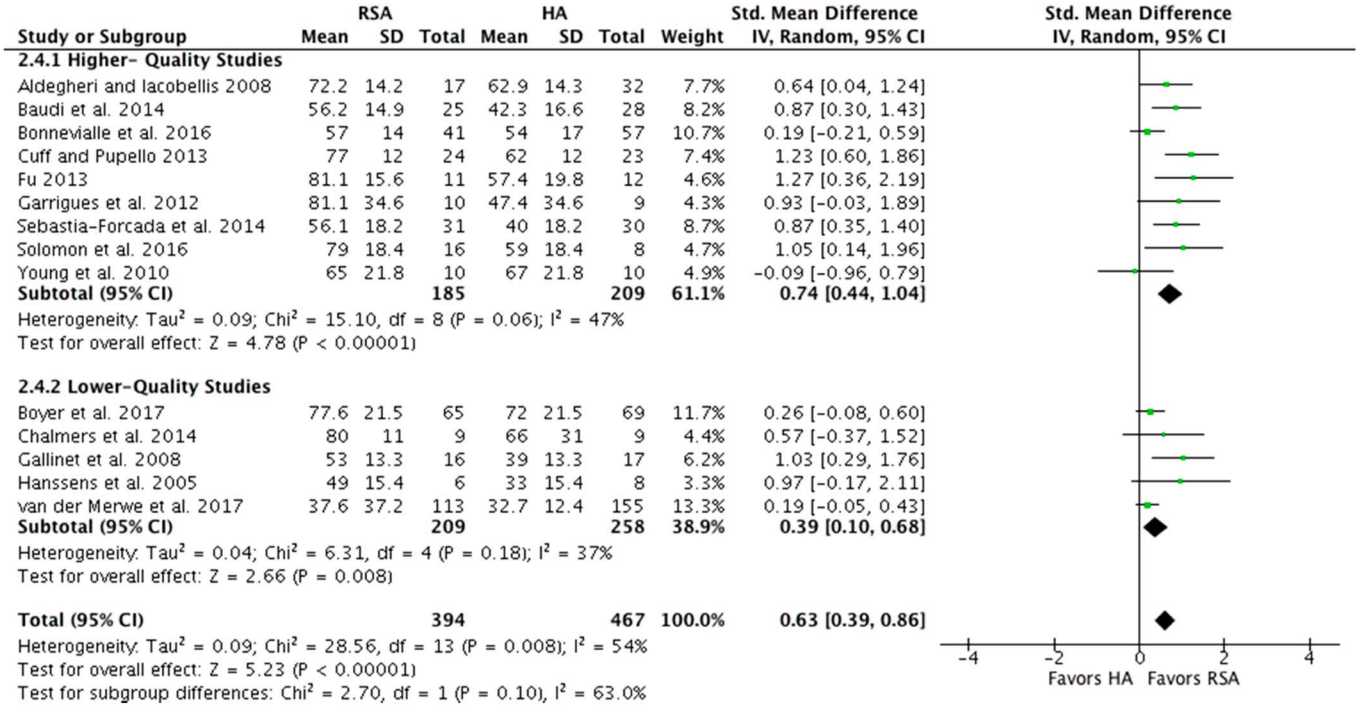

FIGURE 2. Forest plot of combined clinical outcome scores with sensitivity analysis. **Editor's Note:** A color image accompanies the online version of this article.

TABLE 2. Postoperative Complications

Postoperative Complication	HA Events	HA Patients	HA Follow-up (Years)	HA Events/100 Patient-Yrs	RSA Events	RSA Patients	RSA Follow-up (Years)	RSA Events/100 Patient-Yrs
All-cause reoperation								
Aldegheri et al, 2008	1	33	1.58	1.92	1	17	1.25	4.71
Baudi et al, 2014	5	28	2.17	8.23	0	25	2.25	0.00
Bonnevialle et al, 2016	1	57	3.25	0.54	0	57	3.25	0.00
Chalmers et al, 2014	0	9	4.9	0.00	0	9	1.2	0.00
Cuff et al, 2013	3	23	NR	NA	0	24	NR	NA
Gallinet et al, 2008	0	17	1.38	0.00	1	16	1.03	6.07
Garrigues et al, 2012	3	9	4.11	8.11	0	10	3.52	0.00
Hanseens et al, 2005	0	8	NR	NA	1	6	NR	NA
Repetto et al, 2017	7	24	3.52	8.29	3	27	3.48	3.19
Sebastia- Forcada et al, 2014	6	30	2.31	8.66	1	31	2.45	1.32
Solomon, 2016	1	8	NR	NA	2	16	NR	NA
Young, 2010	2	10	NR	NA	0	10	NR	NA
Weighted Average*				4.14				1.58
All-cause revision								
Aldegheri et al, 2008	1	33	1.58	1.92	1	17	1.25	4.71
Baudi et al, 2014	5	28	2.17	8.23	0	25	2.25	0.00
Bonnevialle et al, 2016	1	57	3.25	0.54	0	57	3.25	0.00
Chalmers et al, 2014	0	9	4.9	0.00	0	9	1.2	0.00
Cuff et al, 2013	3	23	NR	NA	0	24	NR	NA
Dillon 2015	30	961	3.83	0.82	1	72	2.35	0.59
Fu 2013	4	12	NR	NA	0	11	NR	NA
Gallinet et al, 2008	0	17	1.38	0.00	1	16	1.03	6.07
Garrigues et al, 2012	3	9	4.11	8.11	0	10	3.52	0.00
Hanseens et al, 2005	0	8	NR	NA	1	6	NR	NA
Repetto et al, 2017	7	24	3.52	8.29	3	27	3.48	3.19
Sebastia- Forcada et al, 2014	6	30	2.31	8.66	1	31	2.45	1.32
van der Merwe et al, 2017	NR	427	NR	1.16	NR	218	NR	0.58
Young, 2010	2	10	NR	NA	0	10	NR	NA
Weighted Average*				1.34				0.98
Aseptic failure								
Aldegheri et al, 2008	1	33	1.58	1.92	1	17	1.25	4.71
Baudi et al, 2014	3	28	2.17	4.94	0	25	2.25	0.00
Bonnevialle et al, 2016	0	57	3.25	0.00	0	57	3.25	0.00
Chalmers et al, 2014	0	9	4.9	0.00	0	9	1.2	0.00
Cuff et al, 2013	3	23	NR	NA	0	24	NR	NA
Dillon 2015	19	961	3.83	0.52	1	72	2.35	0.59
Gallinet et al, 2008	0	17	1.38	0.00	0	16	1.03	0.00
Garrigues et al, 2012	3	9	4.11	8.11	0	10	3.52	0.00
Repetto et al, 2017	7	24	3.52	8.29	2	27	3.48	2.13
Sebastia- Forcada et al, 2014	6	30	2.31	8.66	0	31	2.45	0.00
Young, 2010	1	10	NR	NA	0	10	NR	NA
Weighted Average*				1.06				0.68
Deep infection								
Aldegheri et al, 2008	0	33	1.58	0.00	0	17	1.25	0.00
Baudi et al, 2014	2	28	2.17	3.29	0	25	2.25	0.00
Bonnevialle et al, 2016	1	57	3.25	0.54	0	57	3.25	0.00
Chalmers et al, 2014	0	9	4.9	0.00	0	9	1.2	0.00
Cuff et al, 2013	0	23	NR	NA	0	24	NR	NA
Dillon 2015	15	961	3.83	0.41	1	72	2.35	0.59
Gallinet et al, 2008	0	17	1.38	0.00	1	16	1.03	6.07
Garrigues et al, 2012	3	9	4.11	8.11	0	10	3.52	0.00
Repetto et al, 2017	0	24	3.52	0.00	1	27	3.48	1.06

TABLE 2. (*Continued*) Postoperative Complications

Postoperative Complication	HA Events	HA Patients	HA Follow-up (Years)	HA Events/100 Patient-Yrs	RSA Events	RSA Patients	RSA Follow-up (Years)	RSA Events/100 Patient-Yrs
Sebastia- Forcada et al, 2014	0	30	2.31	0.00	1	31	2.45	1.32
Young, 2010	1	10	NR	NA	0	10	NR	NA
Weighted Average*				0.51				0.79

*Weighted averages did not include studies that did not have follow-up time.
NR, not reported; NA, not applicable.

revisions/100 patient years), although a formal statistical comparison was not completed (Table 2).

DISCUSSION

Summary of Main Results

Our analysis of all included data shows that there is no outcome evaluated in this study in which HA outperforms RSA. We found that RSA is associated with improvements in forward flexion, clinical outcome scores, and risk of reoperation, with no differences in external rotation, tuberosity healing, and deep infection rate. Although our results are limited by short-term follow-up, the aggregate of our findings suggests a clear role for RSA in the reconstructive options for this patient population.

Overall Completeness and Applicability of Evidence

The recent publication of several studies comparing RSA and HA for proximal humerus fractures[11,12,25–28] and the inclusion of previously excluded studies[29,30] has made it possible for us to complete a substantially larger meta-analysis with regard to both number of patients and outcomes examined. We included 15 comparative studies from 421 RSA patients and 492 HA patients for a total of 913 patients in our meta-analysis (Table 1). This data pool is substantially larger than the most recent meta-analyses on this topic, which included 9 studies and 191 RSA patients.[23] This expanded focus allowed us to evaluate ROM and clinical outcomes on a larger scale and provided enough patients to analyze aseptic failure and deep infection rates between RSA and HA; this has not been previously evaluated in the literature. In addition, with the addition of non-English studies to our inclusion criteria, we analyzed studies from 10 different countries, which expands the clinical relevance of our findings to an international level. To our knowledge, this is the largest meta-analysis on the topic in the literature which examines the most outcomes from the largest number of countries. For these reasons, the clinical relevance of our results and the generalizability of our findings are substantial.

Quality of the Evidence

One fundamental limitation of our analysis is the underlying quality of the included studies. Specifically, we were only able to include 1 randomized control trial and otherwise relied on retrospective and prospective cohort studies. Notably, however, sensitivity analyses limiting the included studies to a score of >6 on the NOS did not change our results. Yet, the variation in quality and methodology of these studies likely impacted the magnitude of heterogeneity scores (I^2) that we observed. An I^2 value of 50% is considered moderate heterogeneity,[47] and several of our analyses exceeded this value. When heterogeneity is present, it suggests that caution must be used when considering the results; however, a set cutoff precluding analysis does not exist, and instead, it is necessary to consider the overall consistency of the results.[47] Importantly, the direction of the effect was very consistent among the included studies (13/14 studies favoring RSA for clinical outcomes, 12/12 studies favoring RSA for forward flexion), suggesting that heterogeneity does not impact our overall conclusions. In addition, increased heterogeneity did not seem to affect ASES scores (I^2-18%) and postoperative complication analyses (I^2- 0%).

Strengths and Limitations

Our study had several strengths. First, the search strategy was not limited by language, and we used an international database (EMBASE). Second, we adhered to PRISMA guidelines in reporting our results. Third, we used accepted methods for analysis using the Cochrane Handbook. Moreover, we only included studies in which RSA patients were followed for at least 75% of the time of HA patients. This strengthened the quality of the analysis by eliminating a large source of bias, especially when reporting complications, given the higher risk of observing a complication with increasing follow-up time. Moreover, we systematically ranked our studies based on their ROB according to 2 well-accepted scales (the NOS and the Cochrane ROB tool); importantly, we performed a sensitivity analysis based on these scales and found no difference in our results. Finally, we saw little evidence of publication bias, as seen in our funnel plots in **Supplemental Digital Content 9**, (see **Figure**, http://links.lww.com/JOT/A496); **Supplemental Digital Content 10** (see **Figure**, http://links.lww.com/JOT/A497).

We acknowledge several limitations. First, our included studies did not report a uniform set of outcomes, limiting the number of studies available in the analysis of each outcome. Second, several studies did not report standard deviation values in their data, which necessitated the use of methods to indirectly infer these values. Although these methods are well accepted in the literature, they do potentially introduce increased bias into our results. Third, we are unable to make conclusions about

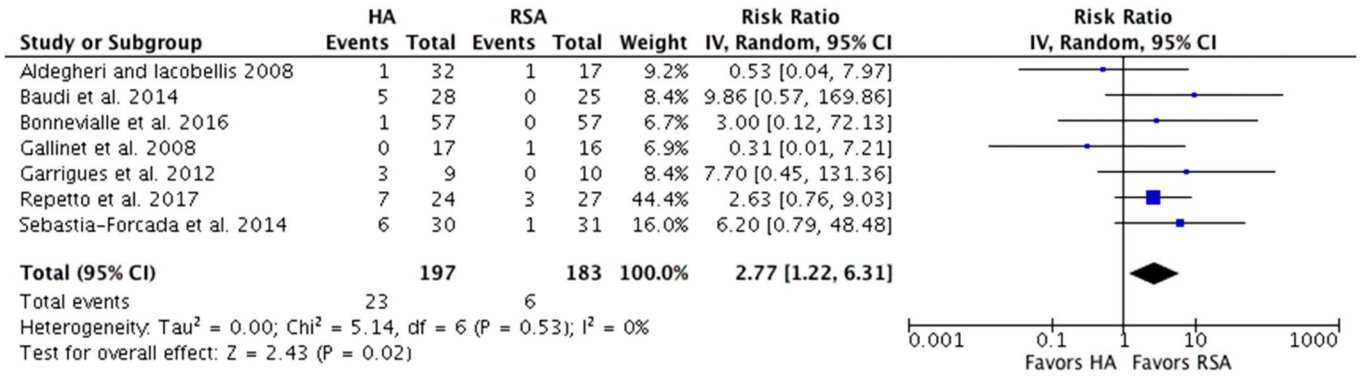

FIGURE 3. Forest plot of all-cause reoperation. **Editor's Note:** A color image accompanies the online version of this article.

long-term comparisons of the interventions because our studies predominantly reported on short-term results. Fourth, our analysis is likely underpowered to compare definitively the infection rates between HA and RSA groups because it is a rare outcome. Similarly, neurovascular injuries and instability events were rare, precluding statistical comparison. Future studies will need to aggregate a larger number of patients to sufficiently study these complications. In addition, we were unable to complete analysis of the recovery timeline after these procedures because of heterogeneous and sparse data. This is an important consideration that requires further research as RSA may require substantially less postoperative physical therapy than HA.[48] Substantial heterogeneity of implant types both within and between studies was observed and prevented meaningful subgroup comparisons between designs. Future research is necessary to understand the differences in outcomes between prosthesis designs. Also, additional studies are necessary to investigate the impact of tuberosity excision on postoperative function, as the clear majority of studies included in our analysis repaired the tuberosities. Finally, our analysis only compares reconstructive options and does not address whether these are superior to ORIF or nonoperative treatment.

Agreements and Disagreements with Other Studies or Reviews

In our study, RSA outperformed HA with regards to forward flexion and abduction, which is consistent with previous meta-analyses.[20–22] Although our finding that active external rotation was not significantly different between groups was similar to a previous review,[20,21] this result stands in contrast to an older review[22] that slightly favored HA. This is perhaps because of our inclusion of more studies that reported on newer implant technology. When examining individual outcome scores, our results were also consistent with previous meta-analyses favoring RSA,[20–23] but the degree of improvement was somewhat less [Constant score SMD 0.6 vs. 1.05,[21] DASH score SMD 0.27 versus 0.57,[21] and ASES 0.86 versus 0.90[20]-1.17[21]]. Of note, both our range of motion and clinical outcome results favoring RSA stand in contrast to conclusions from the original meta-analysis on this topic which demonstrated no differences between groups.[24]

The results of our meta-analysis demonstrating decreased reoperation rates with RSA differ from a large 2017 registry study by Brorson et al[26] which found no significant difference in the risk of revision surgery. In our study, it was apparent that multiple studies reported on HA patients being converted to an RSA to improve function or pain (6/6 HA failures in Sebastia-Forcada et al 2014,[14] 7/7 HA failures in Repetto et al 2017,[25] and 2/3 HA failures in Garrigues et al[44] 2012. Because RSA is a relatively new surgical technology, it seems that revision of HA to RSA for poor function was likely not available in the registry of Brorson et al in the early years,[26] and this could account for the substantial discrepancy between our findings. Our results also differ from the meta-analysis by Namdari et al who reported equivalent reoperation rates between groups,[24] but the inclusion of several case series of HA and reverse patients in that study, instead of only comparative studies directly comparing the 2 interventions, may account for these differences.

CONCLUSION

In conclusion, the results of our meta-analysis suggest that RSA for the treatment of acute proximal humerus fractures in patients older than 65 years of age should be strongly considered as the first-line arthroplasty option. Our results are only applicable for the short and medium term, and thus further work will be required to determine the long-term outcomes of RSA for proximal humerus fractures.

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