JSES International 4 (2020) 156–168

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Clinical outcomes and complications of reverse shoulder arthroplasty used for failed prior shoulder surgery: a systematic review and meta-analysis

Aaron J. Bois, MD, MSc, FRCSC [a,*], Paige Knight, MD [b], Khalifa Alhojailan, MD [b], Kamal I. Bohsali, MD [c]

[a] Section of Orthopaedic Surgery, Department of Surgery, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada
[b] Cumming School of Medicine, University of Calgary, Calgary, AB, Canada
[c] Beaches Division, Jacksonville Orthopaedic Institute, Jacksonville Beach, FL, USA

ARTICLE INFO

Keywords:
Revision
shoulder
arthroplasty
reverse shoulder arthroplasty
salvage
failed treatment

Level of evidence: Level IV; Systematic Review

Background: Reverse shoulder arthroplasty (RSA) is frequently performed in the revision setting as a salvage procedure. The purpose of this study was to report the clinical outcomes and complication, reoperation, and revision rates after revision RSA (RRSA) stratified according to the primary shoulder procedure undergoing revision.

Methods: Four databases (Embase, MEDLINE, SPORTDiscus, and Cochrane Controlled Trials Register) were searched for eligible studies published between January 1985 and September 2017. The primary outcomes of interest included pain, active range of motion, and functional outcome scores. Secondary outcomes included complication, reoperation, and revision rates.

Results: A total of 43 studies (1041 shoulder arthroplasties) met the inclusion criteria, with a mean follow-up period of 43.8 months (range, 31.1-57.2 months). Pain scores improved in all groups; however, none reached statistical significance. Range of motion improved in all groups, except for external rotation in the RSA category. RRSA demonstrated significant improvements in the Simple Shoulder Test score and Constant score (CS) in the group undergoing hemiarthroplasty (HA) for fracture, CS in the group undergoing HA for other indications, and CS in the group undergoing anatomic total shoulder arthroplasty. Pooled complication rates were highest in the failed RSA group (56.2%), followed by the group undergoing HA for other indications (27.7%), total shoulder arthroplasty group (23.6%), soft-tissue repair group (20.6%), open reduction and internal fixation group (19.0%), and group undergoing HA for fracture (13.6%).

Conclusions: Compared with other revision indications, RRSA for failed HA demonstrated the most favorable outcomes, whereas the highest complication and revision rates were observed in the RSA subgroup. This information is useful when establishing patient expectations regarding the risks, benefits, and complication and revision rates of RRSA.

Reverse shoulder arthroplasty (RSA) has historically been used in patients with cuff tear arthropathy.[1] Since Grammont's original reverse implant design in 1985,[4] indications for RSA have continued to expand, including the use of an RSA as a revision procedure for failed prior shoulder surgery.[4,78,80] As the volume of primary shoulder arthroplasties has continued to rise globally,[23,28,37,67,84] so has the number of revision shoulder arthroplasties.[8,20]

RSA as a revision procedure has demonstrated inferior outcomes compared with primary RSA.[3] Revision shoulder surgery using a reverse implant is associated with higher rates of perioperative and postoperative complications including infection, neurologic injury, intraoperative fractures, and instability.[56,65,66,87]

The purpose of this study was to report the clinical outcomes and complication rates after revision RSA (RRSA) stratified according to the primary shoulder procedure undergoing revision by means of a systematic literature review and meta-analysis. We hypothesized that improved subjective and objective outcomes would be found for all revision groups, with the best results observed in patients undergoing revision for a failed soft-tissue procedure (ie, a failed rotator cuff repair, tendon transfer, or

No institutional review board approval was required for this systematic review.

* Corresponding author: Aaron J. Bois, MD, MSc, FRCSC, Section of Orthopaedic Surgery, Department of Surgery, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada.
E-mail address: ajmbois@gmail.com (A.J. Bois).

https://doi.org/10.1016/j.jses.2019.10.108

stabilization procedure). We anticipated that the least favorable surgical outcome with the highest complication rate would occur in patients undergoing revision for a failed RSA.

Materials and methods

Search strategy and selection criteria

A systematic review of the literature was performed following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[48] All studies with level I to IV evidence published in the English language were considered for inclusion. The search for publications from January 1985 through September 2017 was conducted using 4 electronic databases: Embase, MEDLINE, SPORTDiscus, and Cochrane Controlled Trials Register. The search terms used included "shoulder" (Medical Subject Headings [MeSH] term), "arthroplasty" (MeSH term), "revision" (MeSH term), and "reverse." The systematic review was registered in the PROSPERO international prospective register of systematic reviews in December 2017 (registration no. CRD42017080399).

Studies were included if they met the following criteria: (1) revision surgery using an RSA, (2) mean follow-up period of at least 24 months, and (3) reporting of at least 1 primary outcome of interest. When a study included pooled or incomplete data, all authors with available correspondence information were contacted, and the study was included if the study data met our inclusion criteria. If a study included a cohort of patients who met the study criteria and other patients who did not, the study was included and only the data for the patients who met our entry criteria were included. Patient data published in multiple studies were included only once. Studies were excluded if they met the following criteria: (1) insufficient revision surgery details; (2) pooled or combined data (ie, primary and revision) that could not be stratified; and (3) reviews, technique articles, case reports, conference abstracts, and expert-opinion studies. Studies were initially screened by title and abstract, and if a study appeared to be potentially applicable, the full-text article was obtained for full review. If the abstract of a study was not available, the full article was reviewed. Reference lists of identified articles were also reviewed, and all relevant studies were included. All included studies underwent a final review by 2 investigators (A.J.B. and K.I.B.); disagreements during this stage were resolved by a consensus between the same 2 investigators.

Data extraction

Patient demographic characteristics, time from primary to revision surgery, and duration of follow-up were recorded. Intraoperative data including surgical approach, operative duration, blood loss, implant type and manufacturer, and secondary procedures (eg, bone grafting) were recorded. The primary outcome data recorded included (1) pain scores; (2) preoperative and postoperative active range of motion (ROM) including forward elevation (FE), abduction, external rotation in adduction (ER), and internal rotation (IR); and (3) patient-reported outcome measures including the American Shoulder and Elbow Surgeons (ASES) score,[62] Simple Shoulder Test (SST) score,[32,43] and Constant score (CS).[17] IR was recorded as the highest vertebral level that the patient could reach with the thumb extended and was reported on a 1 to 6 scale (1, lateral thigh; 2, buttock; 3, sacroiliac joint; 4, lumbar spine; 5, thoracolumbar junction; and 6, scapula).

The secondary outcome data recorded included (1) complications, (2) reoperations, and (3) revisions. A complication was defined as any intraoperative or postoperative event that was likely to have a negative influence on the patient's outcome.[87] A reoperation was defined as any surgical intervention of the shoulder in which the components were not altered or replaced, whereas revision procedures included partial or complete exchange or removal of the components.[87] All primary and secondary outcome data were stratified according to the 6 index shoulder procedures undergoing revision surgery: hemiarthroplasty (HA) for fracture (HA-fracture) (Fig. 1); HA for other indications (HA-other) such as glenohumeral joint arthritis or cuff tear arthropathy; anatomic total shoulder arthroplasty (TSA, Fig. 2); RSA (Fig. 3); open reduction and internal fixation (ORIF); and soft-tissue repair (STR) such as a failed rotator cuff repair, tendon transfer, or stabilization procedure (Fig. 4).

Risk-of-bias assessment

Study quality was evaluated by 1 investigator (K.I.B.) using the Methodological Index for Non-randomized Studies (MINORS) criteria. Each of the 12 items was graded from 0 to 2. The maximum cumulative scores were 24 for comparative studies and 16 for noncomparative studies.[72]

Statistical analysis

Primary outcome data were compared within and between groups. Secondary outcome data were tabulated as rates and stratified according to the 6 aforementioned shoulder procedures undergoing revision. Statistics were performed separately for categorical variables (ie, exact χ^2 tests) and continuous variables (ie, nonparametric Wilcoxon signed rank and rank sum tests) within and between groups. $P < .05$ was considered statistically significant. All analyses were performed using SAS software (version 9.4; SAS Institute, Cary, NC, USA).

Results

Study selection

The initial database search yielded 919 studies; 416 duplicates were excluded, whereas 1 study was identified by cross-checking reference lists. Thus, 504 studies were screened for inclusion (347 by abstract review and 157 by full-text review) (Fig. 5). Overall, 43 studies (1041 shoulders) met the inclusion and exclusion criteria (Fig. 5). When accounting for studies with combined data sets (ie, pooled data), we included 28 studies for HA (ie, 16 studies for HA-fracture and 12 studies for HA-other), 14 studies for TSA, 9 studies for RSA, 11 studies for ORIF, and 9 studies for STR.

Study characteristics

A total of 1041 shoulders underwent RRSA for the following primary procedures: HA-fracture (n = 284), HA-other (n = 102), TSA (n = 235), RSA (n = 102), ORIF (n = 192), and STR (n = 126) (Table I). The study group included 492 female and 286 male patients (sex was not reported in 263 cases). The mean age at the time of revision surgery was 63.7 years (range, 36-65.2 years). The mean follow-up duration was 43.8 months (range, 31.1-57.2 months). The mean time from primary to revision surgery was 45.7 months (range, 7.6-180 months). We found no statistically significant differences for baseline characteristics including age, sex, follow-up duration, or time between primary and revision surgery among the 6 treatment groups studied.

The indications for revision surgery (in descending order) for all 6 treatment groups studied included rotator cuff deficiency, pain, decreased ROM and/or limited shoulder function, fracture, implant loosening, arthritis, instability, infection, subluxation, avascular necrosis, dislocation, heterotopic ossification, malunion, and implant malposition or migration.

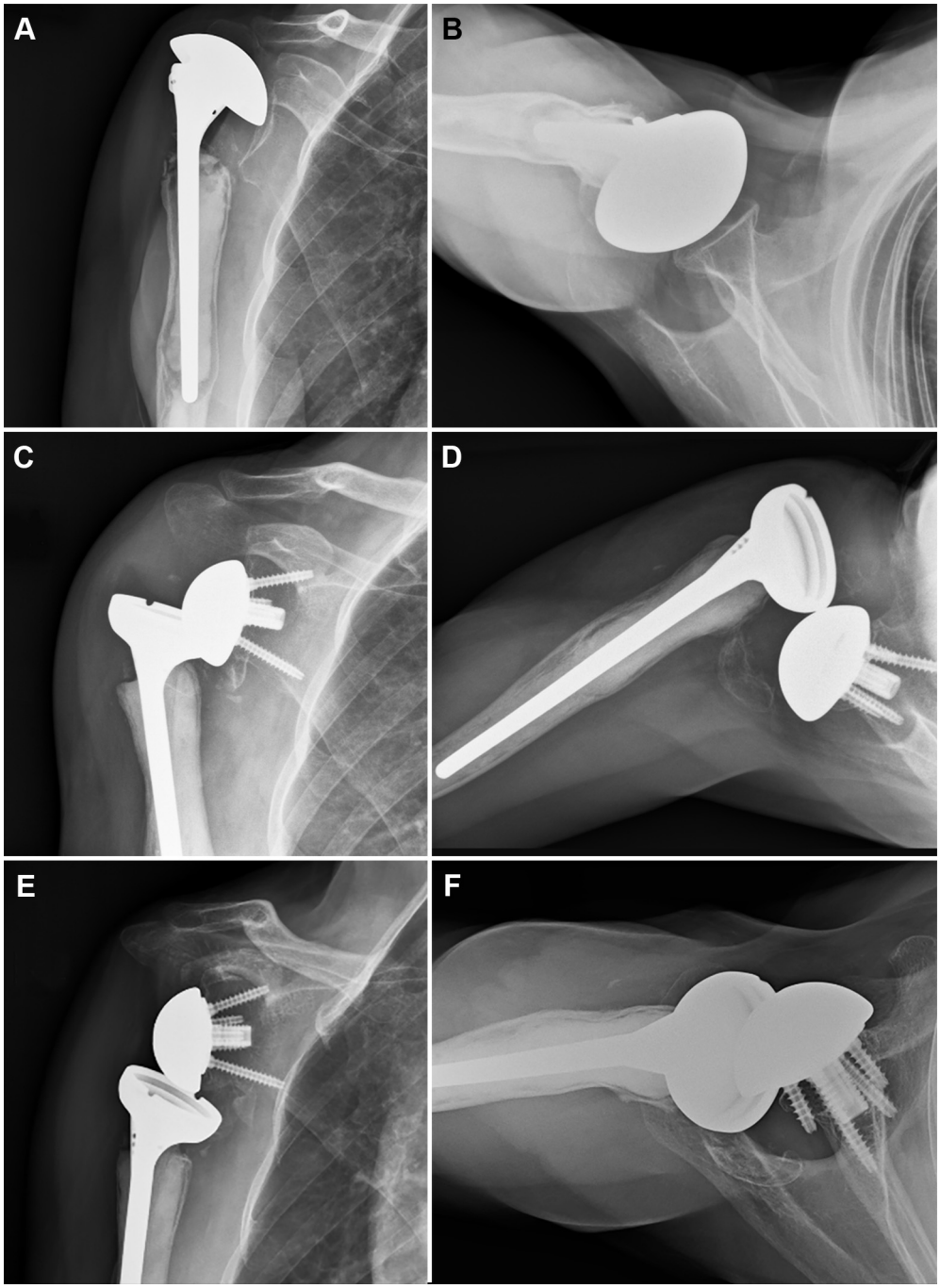

Figure 1 (**A-F**) Clinical example of a 60 year-old female patient referred with a failed hemiarthroplasty for fracture, prosthetic joint infection (*Cutibacterium acnes*), and partial axillary nerve palsy after the index procedure. True anteroposterior (AP) (**A**) and axillary (**B**) radiographs demonstrating superior migration of the humeral head, tuberosity resorption and/or fragmentation, and humeral stem loosening and bone loss. True AP (**C**) and axillary (**D**) radiographs revealing an anterosuperior dislocation of the reverse shoulder arthroplasty 2 weeks after a 2-stage revision procedure that subsequently underwent a successful closed reduction. True AP (**E**) and axillary (**F**) radiographs at the 5-year follow-up visit. Outcome scores completed at last follow-up visit included a total American Shoulder and Elbow Surgeons score of 65.3 and Simple Shoulder Test score of 5. The patient continues to experience neuropathy-related pain due to previous axillary nerve injury.

Study quality

Of the 43 included studies, 24 had level IV evidence, 15 had level III evidence, and 4 had level II evidence (Table I). The mean MINORS score (± standard deviation) of the included studies was 11.9 ± 2.7, which indicated that the quality of evidence was fair (Table I).

Intraoperative details

Multiple RSA prosthetic designs were used at the time of revision surgery, including 3 Grammont-style (ie, medialized [9.3%]) and 10 lateralized (44%) designs; 46.7% of studies did not specify or report the type of prosthesis used. Because of substantial study

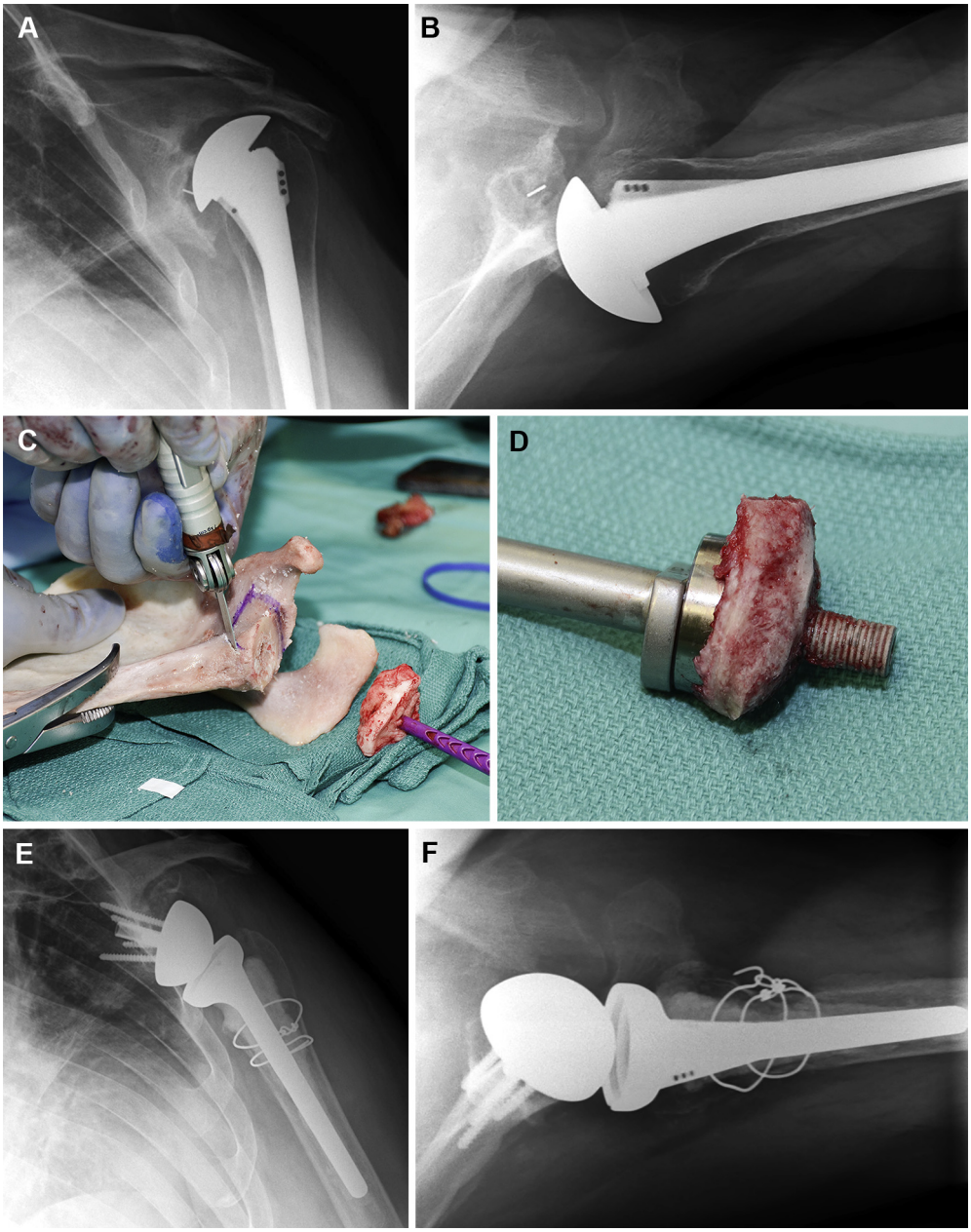

Figure 2 (**A-F**) Clinical example of a 67 year-old male patient with rheumatoid arthritis with a failed anatomic total shoulder arthroplasty. True anteroposterior (**A**) and axillary (**B**) radiographs demonstrating superior migration of the humeral head and posterior instability, respectively, due to a massive posterosuperior rotator cuff tear. (**C**, **D**) Glenoid corticocancellous allograft used to manage a large, uncontained glenoid bone defect. True anteroposterior (**E**) and axillary (**F**) radiographs at the 1-year follow-up visit after reverse shoulder arthroplasty, showing graft incorporation.

heterogeneity and small sample sizes, the data obtained on the type of prosthesis used during the revision procedure (ie, medialized, lateralized, or with a platform stem design) could not be used to further stratify the study results. Other intraoperative data including surgeon experience, surgical approach used, operative duration, blood loss, use of cement during the primary and/or revision procedure, and additional procedures such as a humeral osteotomy to remove a well-fixed humeral stem or humeral or glenoid bone grafting were inconsistently reported. For these reasons, the data were not stratified accordingly.

Primary outcomes

Analysis performed within each category of revision surgery for pain revealed that all treatment groups improved postoperatively; however, none of the groups reached statistical significance (Table II). All groups similarly demonstrated improved ROM postoperatively for all motion parameters, except ER in the RSA group. Statistically significant improvements were found for only the HA-fracture group (FE, 56.4° ± 18.9° [$P < .001$]; abduction, 47.3° ± 10.3° [$P = .008$]); the HA-other group (FE, 53.1° ± 22.1° [$P = .008$]; abduction, 49.2° ± 37.2° [$P = .004$]); the ORIF group (FE, 61.0° ± 20.2° [$P = .031$]); and the STR group (FE, 60.2° ± 21.3° [$P = .03$]; ER, 20.8° ± 18.0° [$P = .016$]) (Table II).

Analysis of patient-reported outcome scores revealed that the HA-fracture group demonstrated statistically significant improvements in the SST score (7.2 ± 10.3, $P = .031$) and Constant shoulder score (CSS) (31.1 ± 7.32, $P = .016$). The HA-other group showed significant improvement in only the CSS (31.5 ± 12.7, $P = .031$), as did the anatomic TSA group (33.8 ± 12.4, $P = .016$). The remaining

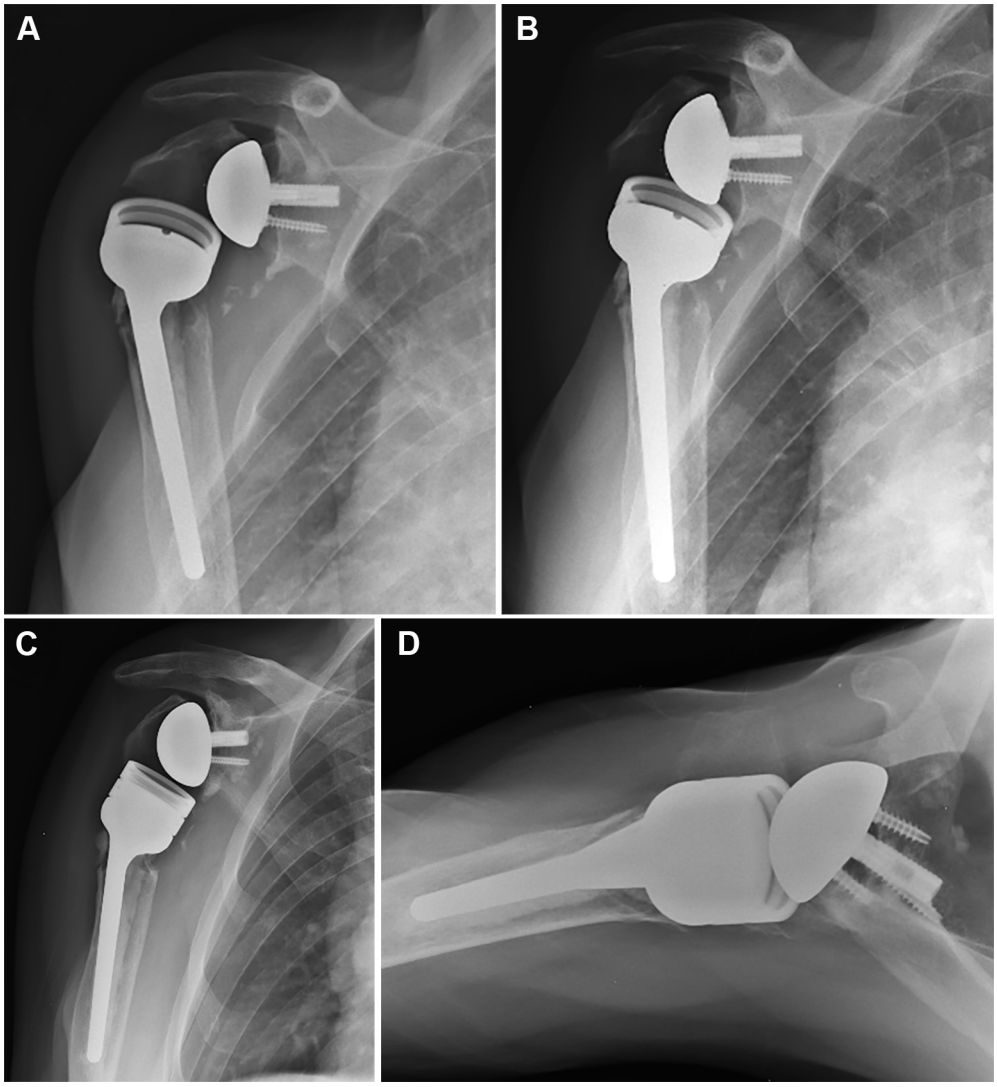

Figure 3 (**A-D**) Clinical example of a 84 year-old male patient with Parkinson disease with a failed anatomic total shoulder arthroplasty due to aseptic glenoid loosening referred for revision shoulder surgery. He underwent a staged revision to reverse shoulder arthroplasty (RSA) because of suspicion of septic glenoid loosening (ie, prosthetic joint infection). (**A**) An anteroposterior (AP) radiograph demonstrates a dislocation of the RSA and baseplate failure after a ground-level fall. (**B**) AP radiograph after spontaneous reduction. True AP (**C**) and axillary (**D**) radiographs after revision RSA, consisting of baseplate repositioning, use of a larger glenosphere, and placement of 2 metallic humeral spacers (off-label use).

groups did not demonstrate statistically significant improvements in the ASES score, SST score, or CSS after RRSA (Table II).

Statistical analysis performed between each category of revision surgery revealed that the HA-fracture group demonstrated significant improvements in FE compared with the STR group (Table III). All other between-group analyses were not statistically significant.

Secondary outcomes

Complications were subcategorized into 11 subtypes with individual and total complication rates calculated among all 6 revision groups (Table IV). The rate of reporting on complications within the 43 included studies was over 80% (Table IV).

In the 16 studies included in the HA-fracture group, a complication rate of 13.6% (36 of 264 cases) was reported; prosthetic joint infection (PJI) (6 of 264 [2.3%]), aseptic humeral stem loosening (6 of 264 [2.3%]), and periprosthetic fracture of the humerus (7 of 264 [2.7%]) were the highest reported complications within this treatment category. The HA-other group (12 studies) demonstrated a complication rate of 27.7% (18 of 65 cases); scapular fracture (8 of 65 [12.3%]) was the highest reported complication within this treatment category. In the 14 studies included in the TSA group, a complication rate of 23.6% (ie, 52 of 220 cases reporting on complications) was found; scapular fracture (12 of 220 cases [5.5%]) was the highest reported complication within this treatment category. In the 9 studies included in the RSA group, a complication rate of 56.2% (ie, 50 of 89 cases reporting on complications) was found; PJI (8 of 89 cases [9%]), baseplate failure (9 of 89 cases [10.1%]), and instability (9 of 89 cases [10.1%]) were the highest reported complications within this treatment category. In the 11 studies included in the ORIF group, a complication rate of 19% (ie, 34 of 179 cases reporting on complications) was found; humeral aseptic loosening (7 of 179 cases [3.9%]) was the highest reported complication within this treatment category. Finally, in the 9 studies included in the STR group, a complication rate of 20.6% (26 of 126 cases reporting on complications) was found; baseplate failure (9 of 126 cases [7.1%]) was the highest reported complication within this treatment category. Radiographic outcomes regarding scapular notching were inconsistently reported within the 43 included studies to permit a meaningful analysis.

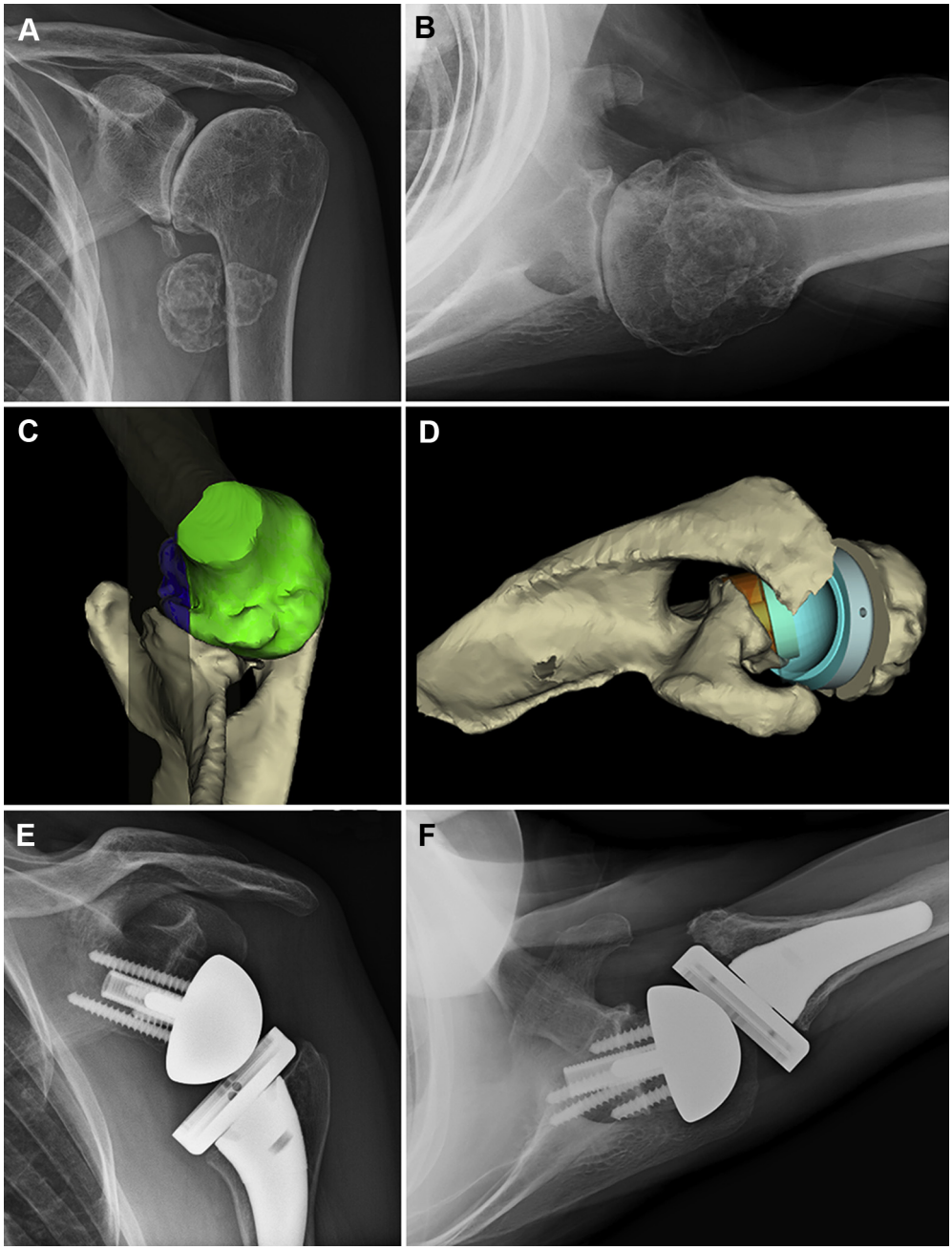

Figure 4 (**A-F**) Clinical example of a 67 year-old female patient with advanced glenohumeral joint arthritis after a previous open stabilization procedure performed as a young adult (ie, instability arthropathy). True anteroposterior (**A**) and axillary (**B**) radiographs demonstrating advanced arthritis, a large loose body in the axillary recess, and a biconcave glenoid deformity. (**C, D**) Three-dimensional software (Glenosys; Imascap, Brest, France) reveals substantial posterior glenoid erosion (approximately 30° of glenoid retroversion) and humeral head subluxation (>90%) with preoperative planning of posterior glenoid bone grafting (ie, bio–reverse shoulder arthroplasty [RSA]). True anteroposterior (**E**) and axillary (**F**) radiographs after revision RSA at the 1-year follow-up visit, demonstrating graft incorporation with concentrically reduced RSA components.

The overall complication rate among all groups was 22.9% (ie, 216 of 943). Instability (31 of 943 [3.3%]) was the highest reported complication among all treatment categories (Table IV). In the combined HA group (ie, HA-fracture and HA-other groups combined) and the TSA group, 32 revisions (11.4%) and 10 revisions (7.1%), respectively, were performed (Table V). In the combined HA group, 13 reoperations (4.6%) were reported. There were 26 reoperations (29.2%) and 17 revisions (19.1%) in the RSA group, 10 reoperations (17.9%) and 17 revisions (9.5%) in the ORIF group, and 7 reoperations (5.6%) and 14 revisions (11.1%) in the STR group (Table V). Detailed data on reoperation and revision procedures were not available for the 43 included studies.

Discussion

Our findings indicate that RRSA performed in patients with a failed HA demonstrated statistically significant improvements in the SST score (HA-fracture group) and CSS (HA-fracture and HA-other groups). In addition, the TSA group revealed a significant improvement in only the CSS.

Forward elevation, ER, and abduction improved across all treatment groups with the exception of ER in the RRSA group. Improvements in ER were greatest after revision of a failed STR, whereas IR improved the least within all groups. Moving forward, consideration should be given to measuring ER in a more functional

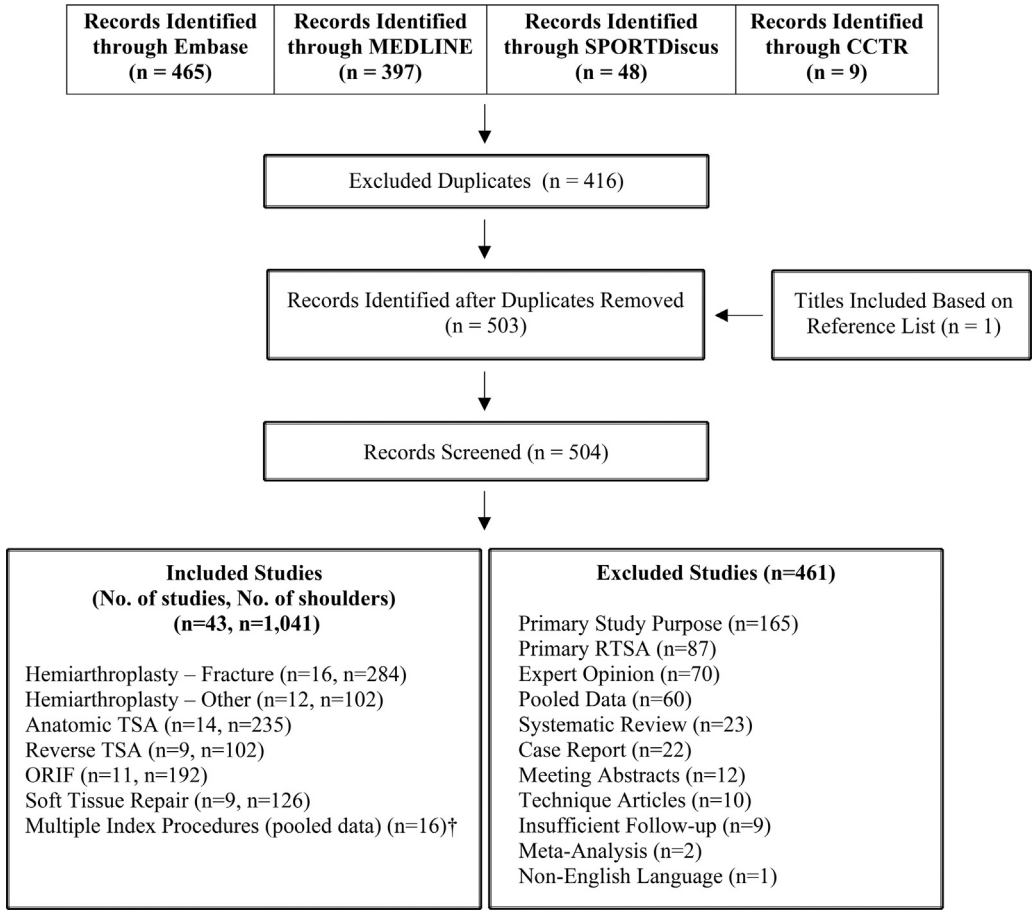

Figure 5 Preferred Reporting Items for Systematic Reviews and Meta-analyses flow diagram of search results with description of cases excluded from studies that underwent full-text review. †Studies with pooled data (ie, multiple revision categories were included). *CCTR*, Cochrane Controlled Trials Register; *TSA*, total shoulder arthroplasty; *ORIF*, open reduction and internal fixation.

position for activities of daily living (ie, abducted ER). A recent systematic review revealed that between 90° and 135° of FE is required to perform personal care.[51] Furthermore, a recent prospective biomechanical study of healthy patients found that the vast majority of the day (97%) is spent with the shoulder below 90° of elevation.[15] Nearly all treatment groups in this review achieved 90° of FE or greater postoperatively. Although statistically significant improvements in abduction were found in only the HA subgroups, all groups except the HA-fracture and RSA groups reached 90° of abduction postoperatively; however, no group increased beyond 120°, which is required for activities of daily living such as placing the hand behind the head and combing hair.[51]

Given the heterogeneity and inconsistent reporting of scoring systems used across studies, direct comparisons were difficult. The results for each score can be assessed individually using previously published minimal clinically important differences (MCIDs). The VAS pain score, ASES pain score, ASES total score, and SST score have been shown to be responsive following primary shoulder arthroplasty with MCIDs of 1.4, 8.0, 20.9 to 23, and 2.4 to 3.0, respectively.[63,70,75,82,86] In this review, the HA-other and TSA groups exceeded the MCID for the VAS pain score. All groups except the ORIF group exceeded the MCID for the ASES pain score. All revision surgery groups exceeded the MCID for the total ASES score, except the HA-other group. Only the HA-fracture and STR groups exceeded the MCID for the SST score. Although the CS does not have clearly defined MCID data in the arthroplasty setting, we found improvements in the postoperative CS in all revision groups.

The overall surgical complication rate in this review was high (22.9%). When we compare complication rates, it is clear that RRSA from a previously performed RSA carries the highest risk of complications, with a reported 56.2% event rate. The RSA group was also found to have the highest complication rates for 4 of 11 complication subtypes (Table IV). This is likely a result of the complex pathology and indications for revision arthroplasty in this setting, such as PJI,[5,34,47,53] instability,[7] and baseplate failure.[30]

Shoulder instability was the highest reported complication among all treatment categories studied (3.3%) (Table IV). RSA remains the only viable surgical option in cases of instability in the primary arthroplasty setting (ie, chronic dislocations)[59] and as a salvage option for recurrent prosthetic instability.[29,79] A recently developed treatment-guiding classification for instability after RSA has been proposed to aid in the management of this challenging problem.[1] Revision shoulder surgery has previously been identified as a commonly associated risk factor for instability after RSA; loss of compression due to inadequate soft-tissue tension, soft-tissue or bony deficiencies, and/or axillary nerve palsy and instability due to mechanical impingement have all been suggested as proposed etiologies of persistent instability after RSA.[1,9,14,16,38,44]

Of the remaining complications reported in this review, PJI, aseptic humeral loosening, baseplate failure, and scapular fracture remained within the top 6 (Table IV). Deep shoulder infection after shoulder arthroplasty occurs in 3.1% of primary cases.[9] In our review, the RSA revision group represented the highest rate of PJI (9.0%). Aseptic humeral stem loosening is a relatively uncommon complication, occurring in 2.9% of revision cases in this review. In

Table I
Characteristics of included studies

Study	Year	Country	Study design	LOE	Revision category	Shoulders, n	Mean age, yr	Mean FU, mo	MINORS score	Comments or notes
Levy et al[40]	2007	USA	Case series	IV	HA for fracture	29	69	24	10	—
Gohlke and Rolf[24]	2007	Germany	Case series	IV	HA for fracture	34	68	31.5	10	—
Chacon et al[13]	2009	USA	Case series	IV	HA for fracture	25	NR	30.2	14	—
Lollino et al[42]	2009	Italy	Prospective cohort	II	HA for fracture	8	NR	24	14	Combined data
Patel et al[57]	2012	USA	Case series	IV	HA for fracture	15	68.1	40.7	12	Combined data
Castagna et al[12]	2013	Italy	Retrospective cohort	III	HA for fracture	18	72.3	32.3	14	Combined data
Werner et al[83]	2013	Germany	Prospective cohort	II	HA for fracture	8	71.8	28.1	12	Combined data
Ortmaier et al[54]	2013	Germany	Retrospective cohort	III	HA for fracture	23	64.3	51	12	Combined data
Uri et al[77]	2014	UK	Case series	IV	HA for fracture	33	63	31	11	—
Wieser et al[85]	2015	Switzerland	Prospective cohort	II	HA for fracture	17	NR	39.1	10	Combined data
Russo et al[64]	2015	Italy	Case series	IV	HA for fracture	3	48.3	60	8	Combined data
Weber-Spickschen et al[81]	2015	Germany	Prospective cohort	III	HA for fracture	2	70	43	9	Combined data
Dezfuli et al[21]	2016	USA	Retrospective cohort	III	HA for fracture	12	66	34	13	Combined data
Otto et al[55]	2017	USA	Case series	IV	HA for fracture	11	48.4	79.5	11	Combined data
Merolla et al[46]	2017	Italy	Case series	IV	HA for fracture	23	NR	38	9	Combined data
Holschen et al[31]	2017	Germany	Retrospective cohort	III	HA for fracture	23	69	24	13	Combined data
Levy et al[41]	2007	USA	Case series	IV	HA for CTA	19	72	45	10	—
Ekelund and Nyberg[22]	2011	Sweden	Case series	IV	HA for CTA	6	61.7	59.3	10	Combined data
Werner et al[83]	2013	Germany	Prospective cohort	II	HA for CTA	5	68.6	29.4	12	Combined data
Wieser et al[85]	2015	Switzerland	Prospective cohort	II	HA for CTA	6	66.7	43.2	14	Combined data
Otto et al[55]	2017	USA	Case series	IV	HA for CTA	5	45	71.2	11	Combined data
Kany et al[36]	2017	France, India	Case series	IV	HA for CTA	5	NR	27.5	12	Combined data
Wieser et al[85]	2015	Switzerland	Prospective cohort	II	HA for arthritis	14	65.5	31.1	14	Combined data
Russo et al[64]	2015	Italy	Case series	IV	HA for arthritis	2	56	60	8	Combined data
Streubel et al[74]	2016	USA	Case series	IV	HH resurfacing	2	61	28.2	12	—
Rasmussen et al[61]	2016	Denmark	Prospective cohort	II	HH resurfacing	30	70	27	11	—
Teusink et al[76]	2014	USA	Case control	III	HA (unspecified)*	2	64	24	16	Combined data
Otto et al[55]	2017	USA	Case series	IV	HA (unspecified)*	6	48.1	57.17	11	Combined data
Ekelund and Nyberg[22]	2011	Sweden	Case series	IV	TSA	1	57	50	10	Combined data
Melis et al[45]	2012	France	Case series	IV	TSA	35	71	47	9	—
Walker et al[79]	2012	USA	Case series	IV	TSA	22	68.6	40	14	—
Patel et al[57]	2012	USA	Case series	IV	TSA	8	68.1	40.7	9	Combined data
Castagna et al[12]	2013	Italy	Retrospective cohort	III	TSA	8	73.6	31.6	12	Combined data
Ortmaier et al[54]	2013	Germany	Retrospective cohort	III	TSA	14	64.2	51	12	Combined data
Teusink et al[76]	2014	USA	Case control	III	TSA	3	67	24	16	Combined data
Wieser et al[85]	2015	Switzerland	Prospective cohort	II	TSA	7	70.1	35.4	14	Combined data
Russo et al[64]	2015	Italy	Case series	IV	TSA	6	58.3	60	8	Combined data
Weber-Spickschen et al[81]	2015	Germany	Retrospective cohort	III	TSA	13	70	43	9	Combined data
Crosby et al[18]	2015	USA	Retrospective cohort	III	TSA	73	67.4	24	9	—
Holschen et al[31]	2017	Germany	Retrospective cohort	IV	TSA	11	73	24	12	Combined data
Otto et al[55]	2017	USA	Case series	IV	TSA	10	45.2	52.2	11	Combined data
Kany et al[36]	2017	France, India	Case series	IV	TSA	24	NR	29.6	12	Combined data
Holcomb et al[30]	2009	USA	Case series	IV	RSA	14	NR	33	12	—
Beekman et al[5]	2010	Belgium	Case series	IV	RSA	11	61.4	24	11	—
Patel et al[57]	2012	USA	Case series	IV	RSA	5	68.1	40.7	9	Combined data
Ortmaier et al[53]	2014	Germany	Retrospective cohort	III	RSA	13	64.2	51	12	—
Middernacht et al[47]	2014	Belgium	Case series	IV	RSA	29	NR	24	11	—
Russo et al[64]	2015	Italy	Case series	IV	RSA	4	62.3	60	8	Combined data
Jacquot et al[34]	2015	France	Case series	IV	RSA	9	71	36	12	—
Black et al[8]	2015	USA	Case series	IV	RSA	16	68.6	58.9	9	—
Otto et al[55]	2017	USA	Case series	IV	RSA	1	48	27	11	Combined data
Lollino et al[42]	2009	Italy	Prospective cohort	II	ORIF	7	NR	24	7	Combined data
Jost et al[35]	2013	Switzerland	Case series	IV	ORIF	13	69	27	10	—
Russo et al[64]	2015	Italy	Case series	IV	ORIF	1	42	60	8	Combined data
Hussey et al[33]	2015	USA	Retrospective cohort	III	ORIF	19	66	24	12	—
Dezfuli et al[21]	2016	USA	Retrospective cohort	III	ORIF	11	66	24	13	Combined data
Shannon et al[71]	2016	USA	Retrospective cohort	III	ORIF	26	72.5	24	20	—
Grubhofer et al[26]	2017	Switzerland	Case series	IV	ORIF	44	68	46	11	—
Statz et al[73]	2017	USA	Case series	IV	ORIF	2	57	45.1	13	Combined data
Merolla et al[46]	2017	Italy	Case series	IV	ORIF	13	NR	31	9	Combined data
Sebastia-Forcada et al[70]	2017	Spain	Case control	III	ORIF	30	73.2	24	18	—
Schliemann et al[68]	2017	Germany	Retrospective cohort	III	ORIF	26	73.3	36	9	—
Boileau et al[10]	2009	France	Retrospective cohort	III	STR	42	70	50	14	—
Mulieri et al[49]	2010	USA	Case series	IV	STR	26	NR	52	18	—
Schneeberger et al[69]	2014	Switzerland	Retrospective cohort	III	STR	19	65	54	12	—
Teusink et al[76]	2014	USA	Case control	III	STR	3	72.3	24	16	Combined data
Raiss et al[60]	2014	Germany, France	Retrospective cohort	III	STR	13	NR	42	10	—
Russo et al[64]	2015	Italy	Case series	IV	STR	3	56.3	60	8	Combined data
Ortmaier et al[52]	2016	Austria	Retrospective cohort	III	STR	8	67.3	97	12	—
Statz et al[73]	2017	USA	Case series	IV	STR	1	63	25	13	Combined data
Otto et al[55]	2017	USA	Case series	IV	STR	11	50.2	68.9	11	Combined data

LOE, level of evidence; *FU*, follow-up; *MINORS*, Methodological Index for Non-randomized Studies; *HA*, hemiarthroplasty; *NR*, not reported; *CTA*, cuff tear arthropathy; *HH*, humeral head; *TSA*, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *ORIF*, open reduction and internal fixation; *STR*, soft-tissue repair.

* HA for unspecified indication.

Table II
Primary outcomes for pain, range of motion, and patient-reported outcome scores

	Shoulders, n: Pre, Post, Δ	Outcome	Preoperative	Postoperative	Change[†]	*P* value
Pain						
HA-fracture	1, 1, 1	CS	2.9 (2.9)	10.0	9.1	1.000
	3, 3, 3	ASES	14.0 (3.8)	33.5 (5.0)	19.5 (2.7)	.250
	4, 6, 4	VAS	5.7 (2.4)	4.1 (2.4)	−1.2 (4.9)	.875
HA-other	2, 4, 4	CS	4.2 (2.8)	11.4 (0.3)	7.1 (3.1)	.125
	4, 4, 4	ASES	13.1 (7.4)	22.8 (12.7)	9.6 (11.9)	.375
	4, 8, 4	VAS	6.8 (2.2)	4.4 (3.0)	−3.1 (5.8)	.375
TSA	3, 3, 3	CS	4.2 (1.3)	11.4 (0.5)	7.1 (1.8)	.250
	2, 2, 2	ASES	20.8 (5.8)	33.0 (13.3)	12.2 (7.4)	.500
	5, 6, 5	VAS	6.5 (2.8)	3.9 (3.2)	−2.9 (5.4)	.625
RSA	0, 0, 0	CS	—	—	—	—
	1, 1, 1	ASES	12.0	37.0	25.0	1.000
	3, 4, 3	VAS	5.6 (2.8)	5.9 (4.0)	−1.1 (6.3)	1.000
ORIF	2, 1, 1	CS	4.5 (3.4)	12.0	5.0	1.000
	1, 1, 1	ASES	7.0	12.0	5.0	1.000
	4, 4, 4	VAS	5.9 (2.7)	5.5 (2.7)	−0.4 (5.5)	1.000
STR	1, 1, 1	CS	3.2	10.9	7.7	1.000
	2, 2, 2	ASES	17.3 (2.3)	35.9 (5.5)	18.5 (3.1)	.500
	2, 4, 2	VAS	4.7 (3.8)	3.8 (3.4)	0.1 (8.8)	1.000
Range of motion						
HA-fracture	12, 13, 11	Forward elevation	50.1 (22.0)	101.1 (23.6)	56.3 (18.9)	<.001[*]
	6, 9, 6	External rotation	10.5 (4.2)	15.9 (11.4)	8.7 (13.0)	.125
	4, 5, 3	Internal rotation	2.8 (1.3)	5.26 (1.30)	2.6 (1.1)	.250
	9, 9, 8	Abduction	46.4 (24.2)	87.50 (11.06)	47.2 (10.2)	.008[*]
HA-other	9, 8, 8	Forward elevation	64.2 (23.9)	114.1 (40.3)	53.1 (22.0)	.008[*]
	8, 6, 6	External rotation	17.7 (16.0)	31.4 (31.7)	20.1 (35.9)	.219
	6, 5, 5	Internal rotation	2.6 (1.9)	3.8 (2.2)	0.8 (3.1)	.688
	10, 9, 9	Abduction	48.7 (11.0)	96.7 (31.6)	49.2 (37.2)	.004[*]
TSA	9, 8, 5	Forward elevation	62.6 (20.7)	118.6 (24.9)	53.1 (35.3)	.063
	6, 6, 5	External rotation	17.4 (7.4)	26.5 (16.1)	7.8 (23.3)	.438
	4, 4, 3	Internal rotation	3.1 (1.6)	5.25 (0.96)	2.1 (2.1)	.500
	7, 6, 4	Abduction	58.8 (25.0)	90. (18.5)	27.9 (24.3)	.125
RSA	5, 5, 5	Forward elevation	43.6 (12.1)	89.7 (47.7)	46.1 (46.4)	.125
	3, 3, 3	External rotation	−1.5 (16.0)	−3.0 (49.4)	−1.5 (33.4)	1.000
	3, 3, 3	Internal rotation	2.0 (1.7)	3.0 (2.6)	1.0 (2.6)	1.000
	4, 4, 4	Abduction	37.5 (10.3)	68.5 (37.6)	31.0 (35.2)	.250
ORIF	7, 8, 6	Forward elevation	64.7 (28.1)	113.4 (15.8)	61.0 (20.2)	.031[*]
	6, 7, 5	External rotation	5.9 (5.5)	22.3 (11.6)	17.8 (17.0)	.063
	5, 6, 4	Internal rotation	1.9 (1.3)	3.5 (1.4)	1.5 (1.6)	.125
	4, 5, 4	Abduction	49.2 (19.9)	90.0 (17.9)	39.7 (7.5)	.125
STR	6, 7, 6	Forward elevation	67.9 (20.6)	127.1 (24.6)	60.2 (21.2)	.031[*]
	7, 8, 7	External rotation	9.7 (17.7)	27.8 (25.2)	20.8 (17.9)	.016[*]
	7, 5, 5	Internal rotation	3.1 (1.0)	4.9 (1.4)	1.3 (0.9)	.125
	4, 4, 4	Abduction	60.1 (16.0)	110.7 (20.2)	50.6 (29.4)	.125
Patient-reported outcome score						
HA-fracture	4, 6, 4	ASES	24.6 (5.0)	58.0 (8.2)	33.4 (5.7)	.125
	6, 8, 6	SST	4.7 (8.9)	10.6 (16.4)	7.1 (10.2)	.031[*]
	7, 10, 7	CSS	18.6 (8.9)	49.2 (11.7)	31.1 (7.3)	.016[*]
HA-other	5, 6, 5	ASES	24.9 (3.9)	44.6 (21.2)	17.4 (20.5)	.188
	4, 2, 2	SST	1.0 (0.8)	2.7 (2.0)	1.7 (2.0)	.500
	6, 6, 6	CSS	20.9 (9.0)	52.4 (15.0)	31.5 (12.6)	.031[*]
TSA	4, 8, 3	ASES	25.1 (10.1)	58.0 (15.0)	35.2 (27.5)	.250
	2, 2, 1	SST	1.3 (1.3)	6.0 (7.2)	−1.4	1.000
	7, 8, 7	CSS	25.2 (9.8)	57.1 (13.9)	33.7 (12.4)	.016[*]
RSA	3, 5, 3	ASES	16.9 (14.9)	45.8 (27.8)	26.5 (24.0)	.500
	3, 5, 3	SST	1.4 (1.2)	15.4 (19.0)	2.2 (2.1)	.500
	4, 4, 4	CSS	31.8 (9.5)	55.1 (15.4)	23.2 (16.4)	.125
ORIF	2, 4, 2	ASES	26.2 (2.1)	57.4 (5.3)	30.3 (11.3)	.500
	2, 4, 2	SST	2.8 (3.0)	5.5 (1.8)	1.2 (1.7)	1.000
	7, 7, 5	CSS	27.4 (17.5)	54.4 (10.3)	33.2 (3.8)	.063
STR	2, 4, 2	ASES	16.5 (19.3)	62.2 (10.5)	44.4 (35.9)	.500
	3, 4, 3	SST	1.5 (0.4)	5.7 (2.0)	4.1 (2.0)	.250
	4, 4, 3	CSS	29.5 (16.9)	68.9 (13.3)	35.2 (8.9)	.250

Pre, preoperative; *Post*, postoperative; *HA-fracture*, hemiarthroplasty for fracture; *CS*, Constant score for pain; *ASES*, American Shoulder and Elbow Surgeons score; *VAS*, visual analog scale score; *HA-other*, hemiarthroplasty for other indications; *TSA*, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *ORIF*, open reduction and internal fixation; *STR*, soft-tissue repair; *SST*, Simple Shoulder Test score; *CSS*, Constant shoulder score.

Data represent the calculated mean (standard deviation) pertaining to the preoperative values, postoperative values, and difference between preoperative and postoperative values postoperative values (i.e., change). It should be noted that the numbers of shoulders are grouped into 3 categories: preoperative, postoperative, and Δ (ie, the number of shoulders available to calculate a difference in the mean). Forward elevation, external rotation and abduction are recorded in degrees. Internal rotation is recorded as the highest vertebral level that the patient can reach with the thumb extended and is reported on a 1 to 6 scale. A dash indicates either the pain scoring system and/or outcome score listed was not used or there were insufficient data to calculate the mean, standard deviation, and *P* value.

[*] Significant *P* value.

[†] The difference between preoperative and postoperative values.

Table III
Between-group analysis for range of motion

	P value					
	HA-fracture	HA-other	Anatomic TSA	Reverse TSA	ORIF	STR
Pre-revision forward elevation						
HA-fracture	—	.16	.09	.67	.10	.06
HA-other	.16	—	1.00	.18	1.00	.86
Anatomic TSA	.09	1.00	—	.11	1.00	.64
Reverse TSA	.67	.18	.11	—	.19	.07
ORIF	.10	1.00	1.00	.19	—	.40
STR	.06	.86	.64	.07	.40	—
Pre-revision external rotation						
HA-fracture	—	.35	.05	.13	.25	.88
HA-other	.35	—	1.00	.15	.19	.60
Anatomic TSA	.05	1.00	—	.05	.04*	.19
Reverse TSA	.13	.15	.05	—	.53	.44
ORIF	.25	.19	.040*	.53	—	.57
STR	.88	.60	.19	.44	.57	—
Pre-revision internal rotation						
HA-fracture	—	.75	.87	.39	.55	.91
HA-other	.75	—	.83	.45	.92	.31
Anatomic TSA	.87	.83	—	.70	.20	.91
Reverse TSA	.39	.45	.70	—	1.00	.24
ORIF	.55	.92	.20	1.00	—	.21
STR	.91	.31	.91	.24	.21	—
Pre-revision abduction						
HA-fracture	—	.22	.13	.41	.41	.13
HA-other	.22	—	.59	.10	.83	.22
Anatomic TSA	.13	.59	—	.11	.92	.78
Reverse TSA	.41	.10	.11	—	.34	.15
ORIF	.41	.83	.92	.34	—	.67
STR	.13	.22	.18	.15	.67	—
Post-revision forward elevation						
HA-fracture	—	.74	.08	.69	.15	.045*
HA-other	.74	—	.44	.61	.50	.24
Anatomic TSA	.08	.44	—	.36	.44	.57
Reverse TSA	.69	.61	.36	—	.43	.17
ORIF	.15	.50	.44	.43	—	.34
STR	.045*	.24	.57	.17	.34	—
Post-revision external rotation						
HA-fracture	—	.36	.39	.71	.18	.45
HA-other	.36	—	1.00	.70	.94	.89
Anatomic TSA	.39	1.00	—	.53	.88	.75
Reverse TSA	.71	.70	.53	—	.82	.76
ORIF	.18	.94	.88	.82	—	.95
STR	.45	.89	.75	.76	.95	—
Post-revision internal rotation						
HA-fracture	—	.39	.89	.17	.12	.90
HA-other	.39	—	.54	.56	.85	.52
Anatomic TSA	.89	.54	—	.25	.11	1.00
Reverse TSA	.17	.56	.25	—	1.00	.31
ORIF	.12	.85	.11	1.00	—	.19
STR	.90	.52	1.00	.31	.19	—
Post-revision abduction						
HA-fracture	—	.96	.23	.26	.51	.10
HA-other	.96	—	.45	.16	.51	.12
Anatomic TSA	.23	.45	—	.47	1.00	.47
Reverse TSA	.26	.16	.47	—	.55	.15
ORIF	.51	.51	1.00	.55	—	.30
STR	.10	.12	.47	.15	.30	—

HA-fracture, hemiarthroplasty for fracture; *HA-other*, hemiarthroplasty for other indications; *TSA*, total shoulder arthroplasty; *ORIF*, open reduction and internal fixation; *STR*, soft-tissue repair.
Between-group comparisons are categorized for forward elevation, external rotation, internal rotation, and abduction. The *P* values represent the statistical differences between groups before and after surgical revision with RSA stratified by the primary procedure.
* Significant *P* value.

a recent systematic review, Grey et al[25] reported a 3.7% risk of aseptic humeral stem loosening after RRSA for a failed arthroplasty. Aseptic glenoid baseplate loosening and failure are catastrophic complications following RSA, with reported rates of 1.2% after primary RSA[6] and 3.0% for RRSA. Improper surgical technique and scapular notching have been implicated as risk factors for glenoid failure.[6,9,27,30,39] Fractures of the acromion and/or scapular spine after RSA occurred in 2.8% of revision cases in this review. In comparison, a recent systematic review of acromial fractures reported an event rate of 4.1%.[58] Increased deltoid tension, superior screw placement during baseplate fixation, and implant design have been proposed as risk factors for acromion and/or scapular spine fractures.[2,9,50,58] The optimal treatment of such fractures remains unclear.[50]

In this study, the overall revision rate for all groups was 9.0% at short- to medium-term follow-up (2 to 5 years). The rate was

Table IV
Secondary outcomes: complications

Primary procedure	Shoulders, n	Complication, n (%)											Total
		PJI	Aseptic loosening*	Baseplate failure	Implant dissociation	Instability or dislocation	H-IO	H-PO	Scapular fracture	Nerve injury	Hematoma	ST injury	
HA-fracture	264	6 (2.3)	6 (2.3)	1 (0.4)	3 (1.1)	5 (1.9)	—	7 (2.7)	2 (0.8)	3 (1.1)	3 (1.1)	—	36 (13.6)
HA-other	65	2 (3.1)	2 (3.1)	2 (3.1)	—	—	—	2 (3.1)	8 (12.3)	—	1 (1.5)	1 (1.5)	18 (27.7)
TSA	220	5 (2.3)	7 (3.2)	7 (3.2)	—	10 (4.5)	—	5 (2.3)	12 (5.5)	2 (0.9)	2 (0.9)	2 (0.9)	52 (23.6)
RSA	89	8 (9.0)	3 (3.4)	9 (10.1)	6 (6.7)	9 (10.1)	1 (1.1)	6 (6.7)	—	2 (2.3)	5 (5.6)	1 (1.1)	50 (56.2)
ORIF	179	2 (1.1)	7 (3.9)	—	—	5 (2.8)	3 (1.7)	6 (3.4)	1 (0.6)	2 (1.1)	4 (2.2)	4 (2.2)	34 (19.0)
STR	126	3 (2.4)	2 (1.6)	9 (7.1)	—	2 (1.6)	—	3 (2.4)	3 (2.4)	1 (0.8)	3 (2.4)	—	26 (20.6)
Total	943	26 (2.8)	27 (2.9)	28 (3.0)	9 (1.0)	31 (3.3)	4 (0.4)	29 (3.1)	26 (2.8)	10 (1.1)	18 (1.9)	8 (0.8)	216 (22.9)

PJI, prosthetic joint infection; *H-IO*, intraoperative periprosthetic fracture of humerus; *H-PO*, postoperative periprosthetic fracture of humerus; *ST*, soft-tissue injury (eg, rotator cuff or deltoid injury); *HA-fracture*, hemiarthroplasty for fracture; *HA-other*, hemiarthroplasty for other indications; *TSA*, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *ORIF*, open reduction and internal fixation; *STR*, soft-tissue repair.
* Humeral aseptic loosening.

highest for those patients undergoing revision of a previously performed RSA (19.1%) and lowest in the TSA group (7.1%). Unfortunately, the modes of implant failure could not be determined in this review. Two recent studies have demonstrated that the 10-year overall prosthetic survival rate for both a Grammont-style RSA and a lateralized RSA is greater than 90%.[3,19] Shoulders that underwent an RSA for a failed arthroplasty were associated with lower functional outcomes and patient-reported outcome scores.[3,19] These findings may be partially attributed to the permanent alteration in shoulder function, including a potential alteration in deltoid power, after a previous shoulder arthroplasty.[3,11] It is interesting to note that, in the study by Cuff et al,[19] patients undergoing an RSA for failure of a previous rotator cuff repair were found to have nearly the same ASES and SST scores as those with primary cuff deficiency and no previous shoulder surgery. In our review, the mean age at the time of revision shoulder surgery was 63.7 years (range, 36-65.2 years), which raises concerns as to the long-term durability of the RRSA procedure performed. Despite the deterioration of clinical outcomes and need for revision surgery over time, there are often few other surgical options remaining for patients in whom previous shoulder surgery has failed.

Limitations of our investigation included unequal group sizes among the 6 treatment categories studied and the substantial heterogeneity in reported outcomes both within and between groups. Because of incomplete data points in several included studies (eg, patient-reported outcome scores), we were unable to weight analyses by study sample sizes. In addition, owing to the small sample sizes and insufficient reporting of data within each of the 6 categories undergoing revision surgery, we were unable to further substratify the data according to the reason for surgical failure or for other surgical variables such as surgical time, blood loss, need for a humeral osteotomy, and/or use of humeral or glenoid bone graft at the time of revision surgery. As with most systematic reviews, there remains the possibility that eligible studies have been disregarded. In our review, 60 potentially eligible studies were excluded based on combined (ie, pooled) data sets (Fig. 5). Although the rate of reporting on complications within the 43 included studies was considered high, complication-related data were missing in 9.4% of shoulders (ie, 98 of 1041). The MINORS criteria confirmed that the included studies represented fair quality. Finally, it is important to note that this review presents only short- to medium-term clinical and radiographic follow-up data.

Table V
Secondary outcomes: reoperations and revisions

Primary procedure	Shoulders, n	Reoperation, n (%)	Revision, n (%)
HA-fracture	225	8 (3.6)	18 (8.0)
HA-other	56	5 (8.9)	14 (25.0)
TSA	140	—	10 (7.1)
RSA	89	26 (29.2)	17 (19.1)
ORIF	179	10 (17.9)	17 (9.5)
STR	126	7 (5.6)	14 (11.1)
Total	832	43 (5.2)	75 (9.0)

HA-fracture, hemiarthroplasty for fracture; *HA-other*, hemiarthroplasty for other indications; *TSA*, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *ORIF*, open reduction and internal fixation; *STR*, soft-tissue repair.
A dash indicates there were insufficient data reported within the included studies.

Conclusion

This review indicates an overall favorable outcome of RRSA when used to revise failed primary shoulder arthroplasty, osteosynthesis of a proximal humeral fracture, and soft-tissue procedures. Complications were common, with the highest rate noted when an RSA was used to revise a failed primary RSA. Understanding surgical outcomes and perioperative risks after revision shoulder surgery is crucial for surgical decision making and establishing patient expectations. Additional research is required to better understand the modes of failure in both the primary and revision arthroplasty settings to improve patient outcomes.

Acknowledgment

The authors thank Eric C. Sayre, PhD (statistical consultant), for his help with analyzing and interpreting the data in this article.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Abdelfattah A, Otto RJ, Simon P, Christmas KN, Tanner G, LaMartina J, et al. Classification of instability after reverse shoulder arthroplasty guides surgical management and outcomes. J Shoulder Elbow Surg 2018;27:e107–18. https://doi.org/10.1016/j.jse.2017.09.031.
2. Ascione F, Kilian CM, Laughlin MS, Bugelli G, Domos P, Neyton L, et al. Increased scapular spine fractures after reverse shoulder arthroplasty with a humeral onlay short stem: an analysis of 485 consecutive cases. J Shoulder Elbow Surg 2018;27:2183–90. https://doi.org/10.1016/j.jse.2018.06.007.
3. Bacle G, Nové-Josserand L, Garaud P, Walch G. Long-term outcomes of reverse total shoulder arthroplasty: a follow-up of a previous study. J Bone Joint Surg Am 2017;99:454–61. https://doi.org/10.2106/JBJS.16.00223.
4. Baulot E, Sirveaux F, Boileau P. Grammont's idea: the story of Paul Grammont's functional surgery concept and the development of the reverse principle. Clin

Orthop Relat Res 2011;469:2425–31. https://doi.org/10.1007/s11999-010-1757-y.
5. Beekman PD, Katusic D, Berghs BM, Karelse A, De Wilde L. One-stage revision for patients with a chronically infected reverse total shoulder replacement. J Bone Joint Surg Br 2010;92:817–22. https://doi.org/10.1302/0301-620X.92B6.23045.
6. Bitzer A, Rojas J, Patten IS, Joseph J, McFarland EG. Incidence and risk factors for aseptic baseplate loosening of reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2018;27:2145–52. https://doi.org/10.1016/j.jse.2018.05.034.
7. Black EM, Roberts SM, Siegel E, Yannopoulos P, Higgins LD, Warner JJ. Failure after reverse total shoulder arthroplasty: what is the success of component revision? J Shoulder Elbow Surg 2015;24:1908–14. https://doi.org/10.1016/j.jse.2015.05.029.
8. Black EM, Roberts SM, Siegel E, Yannopoulos P, Higgins LD, Warner JJ. Reverse shoulder arthroplasty as salvage for failed prior arthroplasty in patients 65 years of age or younger. J Shoulder Elbow Surg 2014;23:1036–42. https://doi.org/10.1016/j.jse.2014.02.019.
9. Bohsali KI, Bois AJ, Wirth MA. Complications of shoulder arthroplasty. J Bone Joint Surg Am 2017;99:256–69. https://doi.org/10.2106/JBJS.16.00935.
10. Boileau P, Gonzalez JF, Chuinard C, Bicknell R, Walch G. Reverse total shoulder arthroplasty after failed rotator cuff surgery. J Shoulder Elbow Surg 2009;18:600–6. https://doi.org/10.1016/j.jse.2009.03.011.
11. Boileau P, Watkinson D, Hatzidakis AM, Hovorka I. Neer Award 2005: the Grammont reverse shoulder prosthesis: results in cuff tear arthritis, fracture sequelae, and revision arthroplasty. J Shoulder Elbow Surg 2006;15:527–40. https://doi.org/10.1016/j.jse.2006.01.003.
12. Castagna A, Delcogliano M, de Caro F, Ziveri G, Borroni M, Gumina S, et al. Conversion of shoulder arthroplasty to reverse implants: clinical and radiological results using a modular system. Int Orthop 2013;37:1297–305. https://doi.org/10.1007/s00264-013-1907-4.
13. Chacon A, Virani N, Shannon R, Levy JC, Pupello D, Frankle M. Revision arthroplasty with use of reverse shoulder prosthesis—allograft composite. J Bone Joint Surg Am 2009;91:119–27. https://doi.org/10.2106/JBJS.H.00094.
14. Chalmers PN, Rahman Z, Romeo AA, Nicholson GP. Early dislocation after reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:737–44. https://doi.org/10.1016/j.jse.2013.08.015.
15. Chapman RM, Torchia MT, Bell JE, Van Citters DW. Assessing shoulder biomechanics of healthy elderly individuals during activities of daily living using inertial measurement units: high maximum elevation is achievable but rarely used. J Biomech Eng 2019;141. https://doi.org/10.1115/1.4042433.
16. Cheung EV, Sarkissian EJ, Sox-Harris A, Comer GC, Saleh JR, Diaz R, et al. Instability after reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2018;27:1946–52. https://doi.org/10.1016/j.jse.2018.04.015.
17. Constant CR, Murley AHG. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987;214:160–4.
18. Crosby LA, Wright TW, Zuckerman JD. Revision total shoulder arthroplasty without humeral component removal: a preliminary report on the role of a platform humeral component. Bull Hosp Jt Dis (2013) 2015;73(Suppl 1):S136–9.
19. Cuff DJ, Pupello DR, Santoni BG, Clark RE, Frankle MA. Reverse shoulder arthroplasty for the treatment of rotator cuff deficiency: a concise follow-up, at a minimum of 10 years, of previous reports. J Bone Joint Surg Am 2017;99:1895–9. https://doi.org/10.2106/JBJS.17.00175.
20. Day JS, Lau E, Ong KL, Williams GR, Ramsey ML, Steven SK. Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. J Shoulder Elbow Surg 2010;19:1115–20. https://doi.org/10.1016/j.jse.2010.02.009.
21. Dezfuli B, King JJ, Farmer KW, Struk AM, Wright TW. Outcomes of reverse total shoulder arthroplasty as primary versus revision procedures for proximal humerus fractures. J Shoulder Elbow Surg 2016;25:1133–7. https://doi.org/10.1016/j.jse.2015.12.002.
22. Ekelund A, Nyberg R. Can reverse shoulder arthroplasty be used with few complications in rheumatoid arthritis? Clin Orthop Relat Res 2011;469:2483–8. https://doi.org/10.1007/s11999-010-1654-4.
23. Erickson BJ, Bohl DD, Cole BJ, Verma NN, Nicholson G, Romeo AA, et al. Reverse total shoulder arthroplasty: indications and techniques across the world. Am J Orthop (Belle Mead NJ) 2018;47. https://doi.org/10.12788/ajo.2018.0079.
24. Gohlke F, Rolf O. Revision of failed fracture hemiarthroplasties to reverse total shoulder prosthesis through the transhumeral approach: method incorporating a pectoralis-major pedicled bone window. J Orthop Trauma 2007;19:185–208. https://doi.org/10.1007/s00064-007-1202-x.
25. Grey B, Rodseth RN, Roche SJ. Humeral stem loosening following reverse shoulder arthroplasty: a systematic review and meta-analysis. JBJS Rev 2018;6:e5. https://doi.org/10.2106/JBJS.RVW.17.00129.
26. Grubhofer F, Wieser K, Meyer DC, Catanzaro S, Schurholz K, Gerber C. Reverse total shoulder arthroplasty for failed open reduction and internal fixation of fractures of the proximal humerus. J Shoulder Elbow Surg 2017;26:92–100. https://doi.org/10.1016/j.jse.2016.05.020.
27. Gutierrez S, Walker M, Willis M, Pupello DR, Frankle MA. Effects of tilt and glenosphere eccentricity on baseplate/bone interface forces in a computational model, validated by a mechanical model, of reverse shoulder arthroplasty. J Shoulder Elbow Surg 2011;20:732–9. https://doi.org/10.1016/j.jse.2010.10.035.
28. Harjula JNE, Paloneva J, Haapakoski J, Kukkonen J, Äärimaa V, Finnish Shoulder Arthroplasty Registry Group. Increasing incidence of primary shoulder arthroplasty in Finland—a nationwide registry study. BMC Musculoskelet Disord 2018;19:245. https://doi.org/10.1186/s12891-018-2150-3.
29. Hernandez NM, Chalmers BP, Wagner ER, Sperling JW, Cofield RH, Sanchez-Sotelo J. Revision to reverse total shoulder arthroplasty restores stability for patients with unstable shoulder prostheses. Clin Orthop Relat Res 2017;475:2716–22. https://doi.org/10.1007/s11999-017-5429-z.
30. Holcomb JO, Cuff D, Petersen SA, Pupello DR, Frankle MA. Revision reverse shoulder arthroplasty for glenoid baseplate failure after primary reverse shoulder arthroplasty. J Shoulder Elbow Surg 2009;18:717–23. https://doi.org/10.1016/j.jse.2008.11.017.
31. Holschen M, Franetzki B, Witt KA, Liem D, Steinbeck J. Is reverse total shoulder arthroplasty a feasible treatment option for failed shoulder arthroplasty? A retrospective study of 44 cases with special regards to stemless and stemmed primary implants. Musculoskelet Surg 2017;101:173–80. https://doi.org/10.1007/s12306-017-0467-y.
32. Hsu JE, Russ SM, Somerson JS, Tang A, Warme WJ, Matsen FA III. Is the Simple Shoulder Test a valid outcome instrument for shoulder arthroplasty? J Shoulder Elbow Surg 2017;26:1693–700. https://doi.org/10.1016/j.jse.2017.03.029.
33. Hussey MM, Hussey SE, Mighell MA. Reverse shoulder arthroplasty as a salvage procedure after failed internal fixation of fractures of the proximal humerus: outcomes and complications. Bone Joint J 2015;97-B:967–72. https://doi.org/10.1302/0301-620X.97B7.35713.
34. Jacquot A, Sirveaux F, Roche O, Favard L, Clavert P, Molé D. Surgical management of the infected reversed shoulder arthroplasty: a French multicenter study of reoperation in 32 patients. J Shoulder Elbow Surg 2015;24:1713–22. https://doi.org/10.1016/j.jse.2015.03.007.
35. Jost B, Spross C, Grehn H, Gerber C. Locking plate fixation of fractures of the proximal humerus: analysis of complications, revision strategies and outcome. J Shoulder Elbow Surg 2013;22:542–9. https://doi.org/10.1016/j.jse.2012.06.008.
36. Kany J, Jose J, Katz D, Werthel JD, Sekaran P, Amaravathi RS, et al. The main cause of instability after unconstrained shoulder prosthesis is soft tissue deficiency. J Shoulder Elbow Surg 2017;26:e243–51. https://doi.org/10.1016/j.jse.2017.01.019.
37. Kim SH, Wise BL, Zhang Y, Szabo RM. Increasing incidence of shoulder arthroplasty in the United States. J Bone Joint Surg Am 2011;93:2249–54. https://doi.org/10.2106/JBJS.J.01994.
38. Kohan EM, Chalmers PN, Salazar D, Keener JD, Yamaguchi K, Chamberlain AM. Dislocation following reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1238–45. https://doi.org/10.1016/j.jse.2016.12.073.
39. Laver L, Garrigues GE. Avoiding superior tilt in reverse shoulder arthroplasty: a review of the literature and technical recommendations. J Shoulder Elbow Surg 2014;23:1582–90. https://doi.org/10.1016/j.jse.2014.06.029.
40. Levy J, Frankle M, Mighell M, Pupello D. The use of the reverse shoulder prosthesis for the treatment of failed hemiarthroplasty for proximal humeral fracture. J Bone Joint Surg Am 2007;89:292–300. https://doi.org/10.2106/JBJS.E.01310.
41. Levy JC, Virani N, Pupello D, Frankle M. Use of the reverse shoulder prosthesis for the treatment of failed hemiarthroplasty in patients with glenohumeral arthritis and rotator cuff deficiency. J Bone Joint Surg Br 2007;89:189–95. https://doi.org/10.1302/0301-620X.89B2.18161.
42. Lollino N, Paladini P, Campi F, Merolla G, Rossi P, Porcellini G. Reverse shoulder prosthesis as revision surgery after fractures of the proximal humerus, treated initially by internal fixation or hemiarthroplasty. Chir Organi Mov 2009;93(Suppl 1):S35–9. https://doi.org/10.1007/s12306-009-0006-6.
43. Matsen FA III, Ziegler DW, DeBartolo SE. Patient self-assessment of health status and function in glenohumeral degenerative joint disease. J Shoulder Elbow Surg 1995;4:345–51.
44. Matthewson G, Kooner S, Kwapisz A, Leiter J, Old J, MacDonald P. The effect of subscapularis repair on dislocation rates in reverse shoulder arthroplasty: a meta-analysis and systematic review. J Shoulder Elbow Surg 2019;28:989–97. https://doi.org/10.1016/j.jse.2018.11.069.
45. Melis B, Bonnevialle N, Neyton L, Levigne C, Favard L, Walch G, et al. Glenoid loosening and failure in anatomical total shoulder arthroplasty: is revision with a reverse shoulder arthroplasty a reliable option? J Shoulder Elbow Surg 2012;21:342–9. https://doi.org/10.1016/j.jse.2011.05.021.
46. Merolla G, Tartarone A, Sperling JW, Paladini P, Fabbri E, Porcellini G. Early clinical and radiological outcomes of reverse shoulder arthroplasty with an eccentric all-polyethylene glenosphere to treat failed hemiarthroplasty and the sequelae of proximal humeral fractures. Int Orthop 2017;41:141–8. https://doi.org/10.1007/s00264-016-3188-1.
47. Middernacht B, Van Tongel A, De Wilde L. Reversed revised: what to do when it goes wrong? Acta Orthop Belg 2014;80:314–21.
48. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. J Clin Epidemiol 2009;62:1006–12. https://doi.org/10.1016/j.jclinepi.2009.06.005.
49. Mulieri P, Dunning P, Klein S, Pupello D, Frankle M. Reverse shoulder arthroplasty for the treatment of irreparable rotator cuff tear without glenohumeral arthritis. J Bone Joint Surg Am 2010;92:2544–56. https://doi.org/10.2106/JBJS.I.00912.
50. Neyton L, Erickson J, Ascione F, Bugelli G, Lunini E, Walch G. Grammont Award 2018: scapular fractures in reverse shoulder arthroplasty (Grammont style): prevalence, functional, and radiographic results with minimum 5-year follow-up. J Shoulder Elbow Surg 2019;28:260–7. https://doi.org/10.1016/j.jse.2018.07.004.
51. Oosterwijk AM, Nieuwenhuis MK, van der Schans CP, Mouton LJ. Shoulder and elbow range of motion for the performance of activities of daily living: a

systematic review. Physiother Theory Pract 2018;34:505–28. https://doi.org/10.1080/09593985.2017.1422206.
52. Ortmaier R, Plachel F, Lederer S, Hitzl W, Auffarth A, Matis N, et al. Reverse shoulder arthroplasty after failed pectoralis major tendon transfer with a minimum follow-up of 5 years. A case series. J Orthop Sci 2016;21:591–5. https://doi.org/10.1016/j.jos.2016.05.001.
53. Ortmaier R, Resch H, Hitzl W, Mayer M, Stundner O, Tauber M. Treatment strategies for infection after reverse shoulder arthroplasty. Eur J Orthop Surg Traumatol 2014;24:723–31. https://doi.org/10.1007/s00590-013-1251-9.
54. Ortmaier R, Resch H, Matis N, Blocher M, Auffarth A, Mayer M, et al. Reverse shoulder arthroplasty in revision of failed shoulder arthroplasty—outcome and follow-up. Int Orthop 2013;37:67–75. https://doi.org/10.1007/s00264-012-1742-z.
55. Otto RJ, Clark RE, Frankle MA. Reverse shoulder arthroplasty in patients younger than 55 years: 2- to 12-year follow-up. J Shoulder Elbow Surg 2017;26:792–7. https://doi.org/10.1016/j.jse.2016.09.051.
56. Padegimas EM, Zmistowski BM, Restrepo C, Abboud JA, Lazarus MD, Ramsey ML, et al. Instability after reverse total shoulder arthroplasty: which patients dislocate? Am J Orthop (Belle Mead NJ) 2016;45:E444–50.
57. Patel DN, Young B, Onyekwelu I, Zuckerman JD, Kwon YW. Reverse total shoulder arthroplasty for failed shoulder arthroplasty. J Shoulder Elbow Surg 2012;21:1478–83. https://doi.org/10.1016/j.jse.2011.11.004.
58. Patterson DC, Chi D, Parsons BO, Cagle PJ Jr. Acromial spine fractures after reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2019;28:792–801. https://doi.org/10.1016/j.jse.2018.08.033.
59. Raiss P, Edwards TB, Bruckner T, Loew M, Zeifang F, Walch G. Reverse arthroplasty for patients with chronic locked dislocation of the shoulder (type 2 fracture sequela). J Shoulder Elbow Surg 2017;26:279–87. https://doi.org/10.1016/j.jse.2016.05.028.
60. Raiss P, Zeifang F, Pons-Villanueva J, Smithers CJ, Loew M, Walch G. Reverse arthroplasty for osteoarthritis and rotator cuff deficiency after previous surgery for recurrent anterior shoulder instability. Int Orthop 2014;38:1407–13. https://doi.org/10.1007/s00264-014-2325-y.
61. Rasmussen JV, Olsen BS, Al-Hamdani A, Brorson S. Outcome of revision shoulder arthroplasty after resurfacing hemiarthroplasty in patients with glenohumeral osteoarthritis. J Bone Joint Surg Am 2016;98:163–7. https://doi.org/10.2106/JBJS.15.00934.
62. Richards RR, An KN, Bigliani LU, Friedman RJ, Gartsman GM, Gristina AG, et al. A standardized method for the assessment of shoulder function. J Shoulder Elbow Surg 1994;3:347–52.
63. Roy JS, Macdermid JC, Faber KJ, Drosdowech DS, Athwal GS. The Simple Shoulder Test is responsive in assessing change following shoulder arthroplasty. J Orthop Sports Phys Ther 2010;40:412–21. https://doi.org/10.2519/jospt.2010.3209.
64. Russo R, Della Rotonda G, Cautiero F, Ciccarelli M. Reverse shoulder prosthesis to treat complex proximal humeral fractures in the elderly patients: results after 10-year experience. Musculoskelet Surg 2015;99(Suppl 1):S17–23. https://doi.org/10.1007/s12306-015-0367-y.
65. Saltzman BM, Chalmers PN, Gupta AK, Romeo AA, Nicholson GP. Complication rates comparing primary with revision reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1647–54. https://doi.org/10.1016/j.jse.2014.04.015.
66. Scarlat MM. Complications with reverse total shoulder arthroplasty and recent evolutions. Int Orthop 2013;37:843–51. https://doi.org/10.1007/s00264-013-1832-6.
67. Schairer WW, Nwachukwu BU, Lyman S, Craig EV, Gulotta LV. National utilization of reverse total shoulder arthroplasty in the United States. J Shoulder Elbow Surg 2015;24:91–7. https://doi.org/10.1016/j.jse.2014.08.026.
68. Schliemann B, Theisen C, Kosters C, Raschke MJ, Weimann A. Reverse total shoulder arthroplasty for type I fracture sequelae after internal fixation of proximal humerus fractures. Arch Orthop Trauma Surg 2017;137:1677–83. https://doi.org/10.1007/s00402-017-2789-5.
69. Schneeberger AG, Muller TM, Steens W, Thur C. Reverse total shoulder arthroplasty after failed deltoid flap reconstruction. Arch Orthop Trauma Surg 2014;134:317–23. https://doi.org/10.1007/s00402-013-1908-1.
70. Sebastia-Forcada E, Lizaur-Utrilla A, Cebrian-Gomez R, Miralles-Munoz FA, Lopez-Prats FA. Outcomes of reverse total shoulder arthroplasty for proximal humeral fractures: primary arthroplasty versus secondary arthroplasty after failed proximal humeral locking plate fixation. J Orthop Trauma 2017;31:236–40. https://doi.org/10.1097/BOT.0000000000000858.
71. Shannon SF, Wagner ER, Houdek MT, Cross WW, Sánchez-Sotelo J. Reverse shoulder arthroplasty for proximal humeral fractures: outcomes comparing primary reverse arthroplasty for fracture versus reverse arthroplasty after failed osteosynthesis. J Shoulder Elbow Surg 2016;25:1655–60. https://doi.org/10.1016/j.jse.2016.02.012.
72. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (MINORS): development and validation of a new instrument. ANZ J Surg 2003;73:712–6.
73. Statz JM, Schoch BS, Sanchez-Sotelo J, Sperling JW, Cofield RH. Shoulder arthroplasty for locked anterior shoulder dislocation: a role for the reversed design. Int Orthop 2017;41:1227–34. https://doi.org/10.1007/s00264-017-3450-1.
74. Streubel PN, Simone JP, Cofield RH, Sperling JW. Revision of failed humeral head resurfacing arthroplasty. Int J Shoulder Surg 2016;10:21–7. https://doi.org/10.4103/0973-6042.174514.
75. Tashjian RZ, Hung M, Keener JD, Bowen RC, McAllister K, Chen W, et al. Determining the minimal clinically important difference for the American Shoulder and Elbow Surgeons score, Simple Shoulder Test, and visual analog scale (VAS) measuring pain after shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:144–8. https://doi.org/10.1016/j.jse.2016.06.007.
76. Teusink MJ, Otto RJ, Cottrell BJ, Frankle MA. What is the effect of postoperative scapular fracture on outcomes of reverse shoulder arthroplasty? J Shoulder Elbow Surg 2014;23:782–90. https://doi.org/10.1016/j.jse.2013.09.010.
77. Uri O, Beckles V, Higgs D, Falworth M, Middleton C, Lambert S. Increased-offset reverse shoulder arthroplasty for the treatment of failed post-traumatic humeral head replacement. J Shoulder Elbow Surg 2014;23:401–8. https://doi.org/10.1016/j.jse.2013.07.041.
78. Wagner ER, Chang MJ, Welp KM, Solberg MJ, Hunt TJ, Woodmass JM, et al. The impact of the reverse prosthesis on revision shoulder arthroplasty: analysis of a high-volume shoulder practice. J Shoulder Elbow Surg 2019;28:e49–56. https://doi.org/10.1016/j.jse.2018.08.002.
79. Walker M, Willis MP, Brooks JP, Pupello D, Mulieri PJ, Frankle MA. The use of the reverse shoulder arthroplasty for treatment of failed total shoulder arthroplasty. J Shoulder Elbow Surg 2012;21:514–22. https://doi.org/10.1016/j.jse.2011.03.006.
80. Wall B, Nové-Josserand L, O'Connor DP, Edwards TB, Walch G. Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg Am 2007;89:1476–85. https://doi.org/10.2106/JBJS.F.00666.
81. Weber-Spickschen TS, Alfke D, Agneskirchner JD. The use of a modular system to convert an anatomical total shoulder arthroplasty to a reverse shoulder arthroplasty: clinical and radiological results. Bone Joint J 2015;97-B:1662–7. https://doi.org/10.1302/0301-620X.97B12.35176.
82. Werner BC, Chang B, Nguyen JT, Dines DM, Gulotta LV. What change in American Shoulder and Elbow Surgeons score represents a clinically important change after shoulder arthroplasty. Clin Orthop Relat Res 2016;474:2672–81. https://doi.org/10.1007/s11999-016-4968-z.
83. Werner BS, Boehm D, Gohlke F. Revision to reverse shoulder arthroplasty with retention of the humeral component. Acta Orthop 2013;84:473–8. https://doi.org/10.3109/17453674.2013.842433.
84. Westermann RW, Pugely AJ, Martin CT, Gao Y, Wolf BR, Hettrich CM. Reverse shoulder arthroplasty in the United States: a comparison of national volume, patient demographics, complications, and surgical indications. Iowa Orthop J 2015;35:1–7.
85. Wieser K, Borbas P, Ek ET, Meyer DC, Gerber C. Conversion of stemmed hemi- or total to reverse shoulder arthroplasty: advantages of a modular stem design. Clin Orthop Relat Res 2015;473:651–60. https://doi.org/10.1007/s11999-014-3985-z.
86. Wong SE, Zhang AL, Berliner JL, Ma CB, Feeley BT. Preoperative patient-reported scores can predict postoperative outcomes after shoulder arthroplasty. J Shoulder Elbow Surg 2016;25:913–9. https://doi.org/10.1016/j.jse.2016.01.029.
87. Zumstein MA, Pined M, Old J, Boileau P. Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2011;20:146–57. https://doi.org/10.1016/j.jse.2010.08.001.