Systematic Review

Surgical Treatment Options for Glenohumeral Arthritis in Young Patients: A Systematic Review and Meta-analysis

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Purpose: The aim of this study was to compare surgical treatment options for young patients with glenohumeral arthritis. **Methods:** A systematic review of the English-language literature was conducted by searching PubMed, EMBASE, and Scopus with the following term: "(shoulder OR glenohumeral) AND (arthritis OR osteoarthritis) AND (young OR younger)." Studies that reported clinical or radiological outcomes of nonbiologic surgical treatment of generalized glenohumeral arthritis in patients younger than 60 years of age were included. Data were extracted to include study and patient characteristics, surgical technique, outcome scores, pain relief, satisfaction, functional improvement, return to activity, health-related quality of life, complications, need for and time to revision, range of motion, and radiological outcomes. Study quality was assessed with the Modified Coleman Methodology Score. **Results:** Thirty-two studies containing a total of 1,229 shoulders met the inclusion criteria and were included in the review. Pain scores improved significantly more after total shoulder arthroplasty (TSA) than after hemiarthroplasty (HA) ($P < .001$). Patient satisfaction was similar after HA and TSA. Revision surgery was equally likely after HA, TSA, and arthroscopic debridement (AD). Complications were significantly less common after AD than after HA ($P = .0049$) and TSA ($P < .001$). AD and TSA afforded better recovery of active forward flexion and external rotation than did HA. At radiological follow-up, subluxation was similarly common after HA and TSA. **Conclusions:** According to current Level IV data, TSA provides greater improvement of pain and range of motion than does HA in the surgical treatment of young patients with glenohumeral arthritis. AD is an efficacious and particularly safe alternative in the short term for young patients with concerns about arthroplasty. **Level of Evidence:** Level IV, systematic review of Level IV studies.

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Degenerative disease of the glenohumeral joint can cause significant pain and disability. Although surgical treatment with prosthetic replacement has been used with excellent success in the elderly, management in younger patients, especially those with high physical demands, remains controversial.[1,2] The initial management of these patients consists of physical therapy, injections, activity modification, or a combination.[3,4] Surgery is indicated when these conservative measures fail to sufficiently alleviate symptoms. Surgical decision making involves consideration of various nonprosthetic and prosthetic treatments.[2] Although total shoulder arthroplasty (TSA) reliably ameliorates symptoms and improves shoulder function,[5-9] this treatment option may lead to component wear, component loosening, and the need for multiple revisions in young patients.[2,10] Although hemiarthroplasty (HA) may be more attractive to young patients, this technique provides significantly less pain relief and functional improvement than does TSA.[9,11]

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HA with biologic glenoid resurfacing (HA + BR) was introduced as an alternative to TSA in younger active patients with glenohumeral arthritis.[12] A number of tissue sources have been used to resurface the glenoid in conjunction with HA, including fascia lata autograft,[13] anterior capsule,[13] lateral meniscus allograft,[14] and Achilles tendon allograft.[10] HA with concentric glenoid reaming, also known as ream and run (R & R),[15] avoids potential concerns about the durability of soft tissue interposition.[16] Arthroscopic debridement (AD) represents a joint-preserving approach that also effectively addresses symptom-producing pathologic conditions aside from the degenerative disease, including loose bodies, biceps tenosynovitis, and disease of the glenoid labrum or rotator cuff, or both.[17] This strategy can be supplemented with one or more arthroscopic procedures, including chondroplasty, capsular release, subacromial decompression, and biceps tenotomy or tenodesis.[17]

The objective of this review was to compare clinical and radiological outcomes across nonbiologic surgical treatment options for glenohumeral arthritis in patients younger than 60 years. It was hypothesized that TSA and AD would provide outcomes superior to other available techniques.

Methods

Eligibility Criteria

The systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Therapeutic studies in human patients were included if they reported outcomes after surgical management of generalized arthritis of the glenohumeral joint in a patient sample with a mean age less than 60 years. Studies that addressed focal chondral defects or other pathologic conditions were excluded. No restrictions were imposed on the publication date, study design, level of evidence, or follow-up interval. Exclusion criteria included case reports or series with a sample size less than 5, laboratory studies, review or technique articles without outcome data, inclusion of heterogeneous procedures without segregation of outcome data, and analysis of the same cohort of patients across multiple studies.

Literature Search

Two independent reviewers (E.T.S., R.M.) searched PubMed, EMBASE, and Scopus to identify relevant English-language studies. The search term was as follows: "(shoulder OR glenohumeral) AND (arthritis OR osteoarthritis) AND (young OR younger)." The resulting study titles and abstracts were reviewed according to the eligibility criteria. Full articles were procured and reviewed for eligible studies, and their references were manually screened in an effort to identify additional studies that may have been missed. The tables of contents of the past 5 years of the *Journal of Shoulder and Elbow Surgery*, the *Journal of Bone and Joint Surgery*, *Clinical Orthopaedics and Related Research*, and the *American Journal of Sports Medicine* were also reviewed. A PRISMA trial flow shows the study selection algorithm (Fig 1).

Data Abstraction

Extracted data included study and patient characteristics, surgical technique, outcome scores, pain relief, satisfaction, functional improvement, return to activity, health-related quality of life, complications, need for and time to revision, range of motion, and radiological outcomes. Patients were stratified into the following treatment groups: HA, TSA, and AD. HA + BR was excluded from the quantitative analysis because it is not well accepted in current practice and has shown great heterogeneity in clinical outcomes.[10,16] R & R was also excluded from the analysis because published studies using this technique have been based on a single patient cohort.[15,18-20]

Data Items

Outcome scores of interest were the American Shoulder and Elbow Surgeons (ASES)[21]; Constant[22]; University of California, Los Angeles[23]; Single Assessment Numeric Evaluation[24]; Simple Shoulder Test[25]; Neer[26]; Disabilities of the Arm, Shoulder, and Hand (DASH)[27]; Subjective Shoulder Value[28]; Rowe[29]; and Shoulder Pain and Disability Index[30] scores. Pain relief was computed using aggregated change from baseline values, standardized to a scale of 10 points, from visual analog scale (VAS), ASES, Constant, and Neer and Cofield[31] pain scores. Health-related quality of life was assessed using the 12-item or 36-item Short Form Health Survey[32,33] and the EuroQol score.[34] Range of motion parameters included active forward flexion (FF), active abduction, active external rotation (ER) in the adducted position, and active internal rotation. Radiological outcomes included joint space, radiolucent lines, implant loosening or malalignment, subluxation, periprosthetic lucency, glenoid erosion, humeral head migration, glenoid erosion, and glenoid morphologic characteristics.

Data Synthesis

Data were aggregated when an outcome was homogeneously reported by at least 3 studies per treatment group. Continuous data were analyzed through computation of the mean and standard deviation, which were frequency weighted for the sample size. Data normality was assessed using the Shapiro-Wilk goodness of fit test. Statistical comparisons were conducted with the Kruskal-Wallis nonparametric test with the Tukey post hoc test for analyses of 3 or more groups or with the Wilcoxon nonparametric test for analyses of 2 groups. Dichotomous data were analyzed using the Pearson χ-square test. Statistical significance was defined by $P < .05$. All statistical analyses were performed with JMP

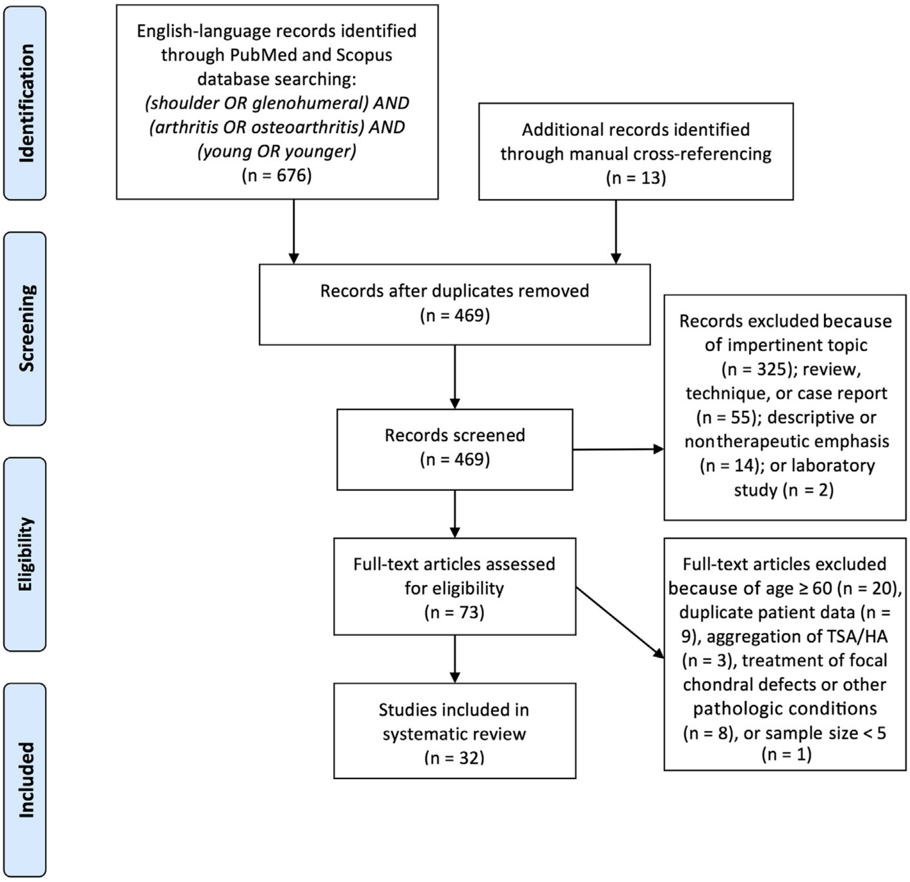

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram describing the inclusion process for the studies in the systematic review.

Pro, version 11.0 (SAS Institute, Cary, NC). All remaining extracted data were reviewed in descriptive fashion. The methodological quality of the studies was analyzed using the Modified Coleman Methodology Score,[35,36] a validated 15-item index with a scale of 0 to 100.

Results

Literature Search

The search of PubMed and Scopus identified 690 studies whose titles and abstracts were preliminarily screened. Full-text manuscripts for 73 studies were procured and reviewed. After application of the eligibility criteria, 32 studies published from 1995 to 2014 remained and were included in the systematic review (Table 1)[10,12-17,31,37-60]; 18 of these studies using HA, TSA, or AD were included in the quantitative synthesis. The mean follow-up interval ranged from 26.7 to 119.7 months across treatment groups. The follow-up rate was between 24.1% and 100% in all studies. The mean Modified Coleman Methodology Score was 34.4 (range, 17 to 53).

Patient Characteristics

The mean age ranged from 43.6 to 47.9 years (male sex, 36.2% to 72.6%) across treatment groups (Table 2). The dominant or right arm was involved in 56.5% to 70.3% of patients. Previous surgery had been performed in 36.2% to 56.0% of patients. The cause of the arthritis was primary osteoarthritis (n = 456), shoulder instability or trauma (n = 150), previous capsulorrhaphy or other shoulder surgery (i.e., chondrolysis) (n = 143), an inflammatory condition (n = 98), avascular necrosis (n = 70), previous fracture (n = 46), idiopathic cause (n = 25), previous septic arthritis (n = 4), glenoid dysplasia (n = 2), or other (n = 21). Staging of arthritis was infrequently reported and was conducted using multiple heterogeneous staging systems. There were some differences in patient demographics and preoperative clinical characteristics across treatment groups, including the follow-up interval, age, sex distribution, proportion of dominant or right arms, and preoperative active FF (Table 3).

Surgical Technique

Patients were treated with HA (n = 459), TSA (n = 203), HA + BR (n = 369), R & R (n = 65), or AD (n = 137). Representative cases of young patients treated with TSA and HA are depicted in Figures 2 and 3. Concomitant procedures were performed

Table 1. Overview of Included Studies

Study	Study Design	No.	Treatment	Follow-up Interval, mo (range)	Follow-up Rate, %	MC Methodology Score
Muh (2014)[59]	Retrospective	16	HA + BR	60 (24-96)	100	38
Denard (2013)[55]	Retrospective	50	TSA	115.5 (60-211)	96.2	42
Hammond (2013)[41]	Retrospective	40	HA, HA + BR	45.6 (12.0-88.8)	80.0	53
Merolla (2013)[45]	Retrospective	60	HA + BR	44 (24-62)	100	35
Millett (2013)[46]	Prospective	28	AD	31.2 (25.2-56.4)	93.3	32
Strauss (2014)[51]	Retrospective	45	HA + BR	33.6 (8.4-98.4)	NR	33
Gadea (2012)[56]	Retrospective	229	HA	134.4 (96-199.2)	61.0	24
Levine (2012)[61]	Retrospective	28	HA	206.4 (156-252)	90.3	42
Bartelt (2011)[38]	Retrospective	66	TSA, HA	72 (24-NR)	100	41
Lollino (2011)[12]	Retrospective	18	HA + BR	NR (24-NR)	NR	26
Saltzman (2011)[15]	Retrospective	65	R & R	43 (24-85)	50.0	37
de Beer (2010)[54]	Retrospective*	32	HA + BR	33.5 (24-52)	51.6	30
Ohl (2010)[47]	Retrospective	19	HA	45.8 (26-108)	90.5	34
Van Thiel (2010)[17]	Retrospective	71	AD	27 (12-90)	87.7	35
Betts (2009)[39]	Prospective	14	TSA	237.6 (198-285.6)	24.1	26
Elhassan (2009)[16]	Retrospective	13	HA + BR	48 (6-102)	NR	35
Lee (2009)[42]	Retrospective	18	HA + BR	57.6 (24-127.2)	81.8	33
McNickle (2009)[44]	Retrospective	13	HA + BR, AD	37.2 (22.8-78)	61.5	30
Savoie (2009)[49]	Prospective	20	HA + BR	NR (36-72)	87.0	47
Wirth (2009)[53]	Retrospective	27	HA + BR	36 (24-60)	90.0	47
Bailie (2008)[37]	Prospective	36	HA	38.1 (24-60)	94.7	44
Levy (2008)[43]	Retrospective	11	TSA	37 (24-66)	100	24
Raiss (2008)[48]	Prospective	21	TSA	84 (60-108)	100	51
Johnson (2007)[57]	Retrospective	16	HA + BR	24	NR	26
Krishnan (2007)[10]	Prospective	36	HA + BR	84 (24-180)	100	35
Nicholson (2007)[14]	Retrospective	30	HA + BR	18 (12-48)	100	39
Richards (2007)[60]	Retrospective	8	AD	13.7	NR	21
Burroughs (2003)[40]	Retrospective	20	HA, TSA	67.2 (26-155)	61.3	29
Sperling (2002)[50]	Retrospective	31	HA, TSA	84 (8.4-252)	93.9	28
Weinstein (2000)[52]	Retrospective	25	AD	34 (12-63)	100	41
Sperling (1998)[31]	Retrospective	114	HA, TSA	147.6 (60-NR)	94.7	39
Burkhead (1995)[13]	Prospective	6	HA + BR	28 (24-34)	42.9	21

AD, arthroscopic debridement; BR, biologic resurfacing; HA, hemiarthroplasty; MC, Modified Coleman; NR, not reported; R & R, ream and run; TSA, total shoulder arthroplasty.

*The study of de Beer et al. was a retrospective study of prospectively collected data.

in 16 of 32 studies (Appendix Table 1, available at www.arthroscopyjournal.org).[14,16,17,31,37,38,45-47,50-52] Studies that used HA or TSA variably used anatomic versus resurfacing prostheses, cemented versus uncemented prostheses, and metal-backed versus polyethylene components. AD consisted of chondral debridement with or without associated procedures such as capsular release, subacromial decompression, loose body removal, and biceps tenodesis.

Subjective Outcomes

Seventeen studies reported VAS pain scores,[10,14,16,17,37,39,41,42,44-46,49,51,53,54,57,59] 4 reported Constant pain scores,[47,48,55,56] one reported ASES pain scores,[43] and one reported Neer and Cofield pain scores[31] (Appendix Tables 2 and 3, available at www.arthroscopyjournal.org). Improvement in pain status, using an aggregate of standardized pain scores, was significantly greater after TSA than after HA ($P < .001$). Thirteen studies evaluated patient satisfaction,[10,12,14,37,38,40,42,43,45,48,49,52,55] which was similar after HA and TSA ($P = .5273$).

Complications

The overall complication rate was reported or calculable in 20 studies.[10,12-14,16,31,37-39,42,46-48,50-56] There were significantly fewer complications after AD than after HA ($P = .0049$) and TSA ($P < .001$). Fewer complications also occurred after HA than after TSA ($P = .0042$). Twenty-eight studies reported the proportion of patients requiring revision surgery,[10,14,16,17,37-41,43-46,48-51,53-57,59,61] which was similar across treatment groups ($P = .9023$).

Range of Motion

Twenty-two studies reported the range of active FF (Appendix Table 4, available at www.arthroscopyjournal.org).[10,13,14,17,38,41-46,48,49,51-55,57-60] Final FF was significantly higher after AD ($P < .001$) and significantly lower after HA ($P < .001$) than after all other treatments. The improvement in FF was greater after TSA than after AD ($P < .001$) and greater after AD than after HA ($P = .0107$). Ten studies reported the range of active ER in the adducted position.[10,13,14,17,31,38,39,41-53,55] The final ER was significantly higher after AD than after TSA ($P < .001$).

Table 2. Demographic Characteristics of Included Studies

Study	N	Treatment	Age, yr (range)	Male Sex, %	Dominant or Right Arm, %	Previous Surgery, %
Muh (2014)[59]	16	HA + BR	36.1 (14-45)	75	NR	18.8
Denard (2013)[55]	50	TSA	50.5 (35-55)	56.0	74.0	NR
Hammond (2013)[41]	20, 20	HA, HA + BR	33.9 (16.8-49.6)	50	40	50.0, 60.0
Merolla (2013)[45]	60	HA + BR	48 (8.4)	60.0	71.7	NR
Millett (2013)[46]	28	AD	52 (33-68)	79.3	NR	NR
Strauss (2014)[51]	45	HA + BR	42.2 (18.1-60.2)	73.3	58.5	71.1
Gadea (2012)[56]	229	HA	59 (16-82)	31.0	57	NR
Levine (2012)[61]	28	HA	55.5 (26-81)	50	NR	NR
Bartelt (2011)[38]	46, 20	TSA, HA	49 (21-55), 49 (26-55)	71.7, 80.0	NR	45.6, 20.0
Lollino (2011)[12]	18	HA + BR	32 (23-53)	100	NR	72.2
Saltzman (2011)[15]	65	R & R	48 (22-55)	86.2	NR	71.9
de Beer (2010)[54]	32	HA + BR	57.5 (36-69)	68.8	68.8	15.6
Ohl (2010)[47]	19	HA	54.5 (42-79)	26.7	NR	NR
Van Thiel (2010)[17]	71	AD	47 (18-77)	66.2	NR	20 surgical procedures
Betts (2009)[39]	14	TSA	47.7 (21.0-67.0)	8.3	NR	NR
Elhassan (2009)[16]	13	HA + BR	34 (18-49)	69.2	76.9	76.9
Lee (2009)[42]	18	HA + BR	54.8 (35-68)	71.4	38.1	NR
McNickle (2009)[44]	8, 5	HA + BR, AD	19.7 (13.1-33.8)	70.0	NR	100, 100
Savoie (2009)[49]	20	HA + BR	32 (15-58)	NR	60.0	60.0
Wirth (2009)[53]	27	HA + BR	43 (24-53)	63.3	63.0	55.6
Bailie (2008)[37]	36	HA	42.3 (28-54)	NR	NR	NR
Levy (2008)[43]	11	TSA	39 (16-64)	54.5	NR	100
Raiss (2008)[48]	21	TSA	55 (37-60)	57.1	61.9	0
Johnson (2007)[57]	16	HA + BR	< 50	NR	NR	NR
Krishnan (2007)[10]	36	HA + BR	51 (30-75)	88.2	91.7	44.4
Nicholson (2007)[14]	30	HA + BR	42 (18-52)	66.7	NR	73.3
Richards (2007)[60]	8	AD	55.5	100	NR	NR
Burroughs (2003)[40]	16, 4	HA, TSA	38.6 (23-50)	NR	68.4	15.8
Sperling (2002)[50]	10, 21	HA, TSA	46 (21-72)	NR	NR	96.8
Weinstein (2000)[52]	25	AD	46 (27-72)	NR	56	32.0
Sperling (1998)[31]	78, 36	HA, TSA	39 (19-50), 41 (22-50)	NR	NR	33.3, 13.9
Burkhead (1995)[13]	6	HA + BR	48 (33-54)	NR	83.3	66.7

AD, arthroscopic debridement; BR, biologic resurfacing; HA, hemiarthroplasty; NR, not reported; R & R, ream and run; TSA, total shoulder arthroplasty.

Radiological Outcomes

The rate of subluxation, which was reported by 8 studies,[14,31,38,42,43,47,50,53] was the only radiological outcome for which data could be pooled in multiple groups (Appendix Table 5, available at www.arthroscopyjournal.org). Subluxation was similarly common after HA and TSA ($P = .1676$).

Discussion

The impetus for this systemic review was the lack of consensus on the optimal management of glenohumeral arthritis in younger patients with higher activity levels. AD, HA + BR, and R & R are alternative surgical treatments that have been proposed in this patient demographic instead of the traditional options of TSA and HA. Therefore, the goal of this review was to compare clinical and radiological outcomes across surgical treatment options in the setting of glenohumeral arthritis in the young patient younger than 60 years of age. Level IV data from 32 studies, containing 1,229 shoulders in total, were included in this systematic review and meta-analysis to address this question.

The findings of this review suggest that TSA and AD provide better clinical outcomes than does HA in the surgical treatment of glenohumeral arthritis in young patients. AD is clinically efficacious in the short term while avoiding short-term complications and long-term prosthetic wear, loosening, and bone loss associated with arthroplasty. In particular, TSA provided significantly greater mean improvement in standardized pain scores than did HA. Patients were likely to be satisfied equally after undergoing HA or TSA. Complications were significantly less common after AD than after HA and TSA, although the rate of revision surgery was between 18% and 20% after all 3 procedures. AD and TSA afforded better recovery of active FF and ER than did HA. At radiological follow-up, subluxation was observed at a similar rate after HA and TSA.

HA and TSA are the most common surgical treatment strategies for degenerative disease of the glenohumeral joint in the general population.[11] Advantages of HA over TSA include reduced operative time,[31] blood loss,[31] and technical difficulty.[11] There are concerns about long-term clinical outcomes with HA[58] because of glenoid erosion, subchondral sclerosis, and loss of joint space, all of which may potentially necessitate later conversion to TSA.[61-64] Because conversion of

Table 3. Aggregated Demographic and Outcome Statistics for Included Studies

	No. of Studies	No. of Shoulders	HA	TSA	AD
Demographics					
Number of studies	–	–	9	8	5
No. of shoulders	–	–	459	203	137
Follow-up interval, mo (SD)	30	1,139	119.7 (43.9) T, A	108.0 (46.7) A	26.7 (7.3)
Age, yr (SD)	31	1,031	53.9 (7.9) T, A	48.8 (4.0)	47.3 (6.1)
Male sex, %	24	917	36.2	56.3 H	72.6 H, T
Dominant or right arm, %	14	647	56.5	70.3 H	NA
Previous surgery, %	20	605	36.3	36.2	NA
Outcome scores					
ASES, preoperatively	12	322	NA	NA	NA
ASES, postoperatively (SD)	15	408	71.0 (16.3)	NA	NA
ASES, Δ	12	322	NA	NA	NA
Constant, preoperatively	9	343	NA	NA	NA
Constant, postoperatively (SD)	12	456	62.2 (2.5)	NA	NA
Constant, Δ	9	343	NA	NA	NA
SST, preoperatively	8	252	NA	NA	NA
SST, postoperatively	9	300	NA	NA	NA
SST, Δ	8	252	NA	NA	NA
Subjective outcomes					
VAS, preoperatively	14	416	NA	NA	NA
VAS, postoperatively	17	484	NA	NA	NA
VAS, Δ	14	416	NA	NA	NA
Pain status, Δ (SD)	24	801	3.4 (1.6)	4.7 (0.8) H	NA
Pain improvement, %	12	332	88.5	NA	NA
Functional improvement, %	5	102	NA	NA	NA
Satisfaction, %	13	410	84.7	81.2	NA
Complications					
Overall complications, %	20	811	13.2 A	23.7 H, A	0
Need for revision, %	28	1,001	18.3	19.1	20.2
Time to revision, yr (SD)	13	485	5.1 (2.7)	NA	NA
Range of motion					
Forward flexion, preoperatively (SD)	19	566	106.5° (5.3) T	97.9° (9.9)	124.3° (18.6) H, T
Forward flexion, postoperatively (SD)	22	625	130.2° (12.1)	136.2° (11.2) H	156.8° (8.1) H, T
Forward flexion, Δ (SD)	19	566	23.6° (12.8)	38.3° (10.5) H, A	29.7° (15.0)
Abduction, preoperatively (SD)	8	280	NA	62.3° (12.4)	NA
Abduction, postoperatively (SD)	9	298	NA	100.8° (19.9)	NA
Abduction, Δ (SD)	8	280	NA	38.5° (12.1)	NA
External rotation, preoperatively (SD)	8	231	NA	NA	36.5° (16.6)
External rotation, postoperatively (SD)	10	302	NA	34.4° (5.5)	61.4° (5.5) T
External rotation, Δ (SD)	8	231	NA	NA	24.9° (14.9)
Radiological outcomes					
Joint space, mm	8	278	NA	NA	NA
Radiolucent lines, %	8	270	NA	53.8	NA
Implant loosening or malalignment, %	8	245	NA	28.7	NA
Subluxation, %	8	245	44.0	33.3	NA

Statistical significance: H = greater than hemiarthroplasty, T = greater than total shoulder arthroplasty, and A = greater than arthroscopic debridement.

AD, arthroscopic debridement; ASES, American Shoulder and Elbow Surgeons; HA, hemiarthroplasty; NA, not analyzed (limited data); SD, standard deviation; SST, Simple Shoulder Test; TSA, total shoulder arthroplasty; VAS, visual analog scale.

humeral head replacement to TSA appears to provide suboptimal outcomes in comparison with initial primary TSA,[65,66] an important consideration in surgical planning is the feasibility of eventual conversion to another technique. Although AD may not alter the progression of degenerative disease, it may be a worthy alternative strategy because of its potential to alleviate symptoms, improve function, and delay arthroplasty while causing minimal surgical morbidity, [17,67] as substantiated by its 0% complication rate in this review.

Limitations

There are limitations to this systematic review, including the quality of the evidence on which it is based. Because all included studies were of Level IV evidence, the likelihood of methodological bias was increased. The majority of studies contained one or more demonstrable biases, including selection, detection, attrition biases, or a combination. The methodological quality of these Level IV studies was poor according to the validated Modified Coleman Methodology Score. Although a mean age younger than 60

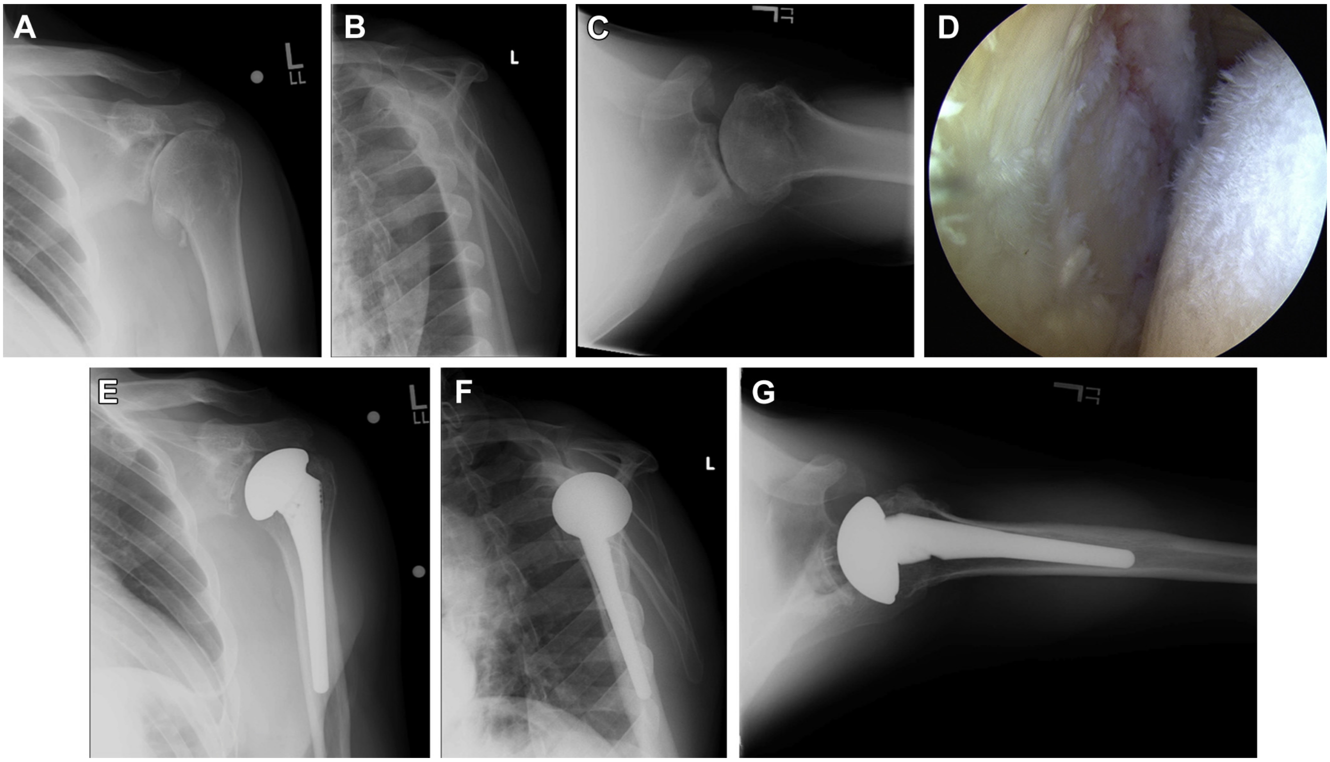

Fig 2. This 42-year-old man sustained a motor vehicle accident with an associated glenohumeral dislocation. An outside physician performed a labral repair, and the patient subsequently experienced intractable shoulder dysfunction, pain, and stiffness. Radiographs were obtained, including (A) Grashey anteroposterior (AP), (B) scapular Y lateral, and (C) axillary lateral views, which showed joint space narrowing, osteophyte formation, and subchondral cyst formation. (D) Arthroscopy was performed and revealed chondrolysis. The patient underwent total shoulder arthroplasty, which provided pain relief and improved range of motion. Postoperative films at 6 months showed a well-fixed and well-aligned prosthesis on (E) Grashey AP, (F) scapular Y lateral, and (G) axillary lateral views.

years was required for study inclusion in this review, a minority of elderly patients was likely included. As a result of limited or nonuniformly reported data, it was not possible to analyze certain outcomes for every treatment group. Our requirement of 3 studies per treatment group for pooling of an outcome limited the number of comparisons that were possible but theoretically decreased bias. The analyses yielded discordant findings in some cases for change from baseline versus postoperative values, which complicates interpretation. It has been previously noted that patients undergoing TSA may have particularly poor preoperative scores, making it easier to show statistically significant improvements from baseline.[11] This issue is difficult to avoid when using lower level evidence, in which preoperative parameters may be highly variable, rather than prospective controlled trials. However, our analysis of preoperative values, when amenable to pooling, allows contextualization of these findings. It was not possible to compare pooled outcome scores across treatment groups because no single outcome score was reported by 3 or more studies in the TSA and AD groups. The inconsistent use of several scoring systems is a limitation of the existing literature. Significant clinical heterogeneity was present within and across studies, including the disease process, coexisting pathologic conditions, previous surgery, concomitant procedures, implant type if applicable, and postoperative management. Importantly, the significant variation in the mean follow-up interval across the treatment groups must be taken into account when interpreting the findings of this review, particularly when considering that the long-term clinical benefit of AD has yet to be established. Indeed, the mean follow-up interval was 108 months and 120 months for patients treated with HA and TSA, respectively, versus 27 months for those who underwent AD. It is possible that arthroscopically treated patients had lesser stages of arthritis, but this information was infrequently and nonuniformly reported by the studies. HA + BR was excluded from the pooled analyses because of excessive variability in its clinical outcomes, including high failure rates in recent reports,[16,59] leading to its increasing disuse at some institutions. R & R was also not amenable to quantitative analysis because studies using this technique have analyzed a single patient cohort.[15,18-20] Type II error is possible for those comparisons in which no significant difference was found, but given that most comparisons

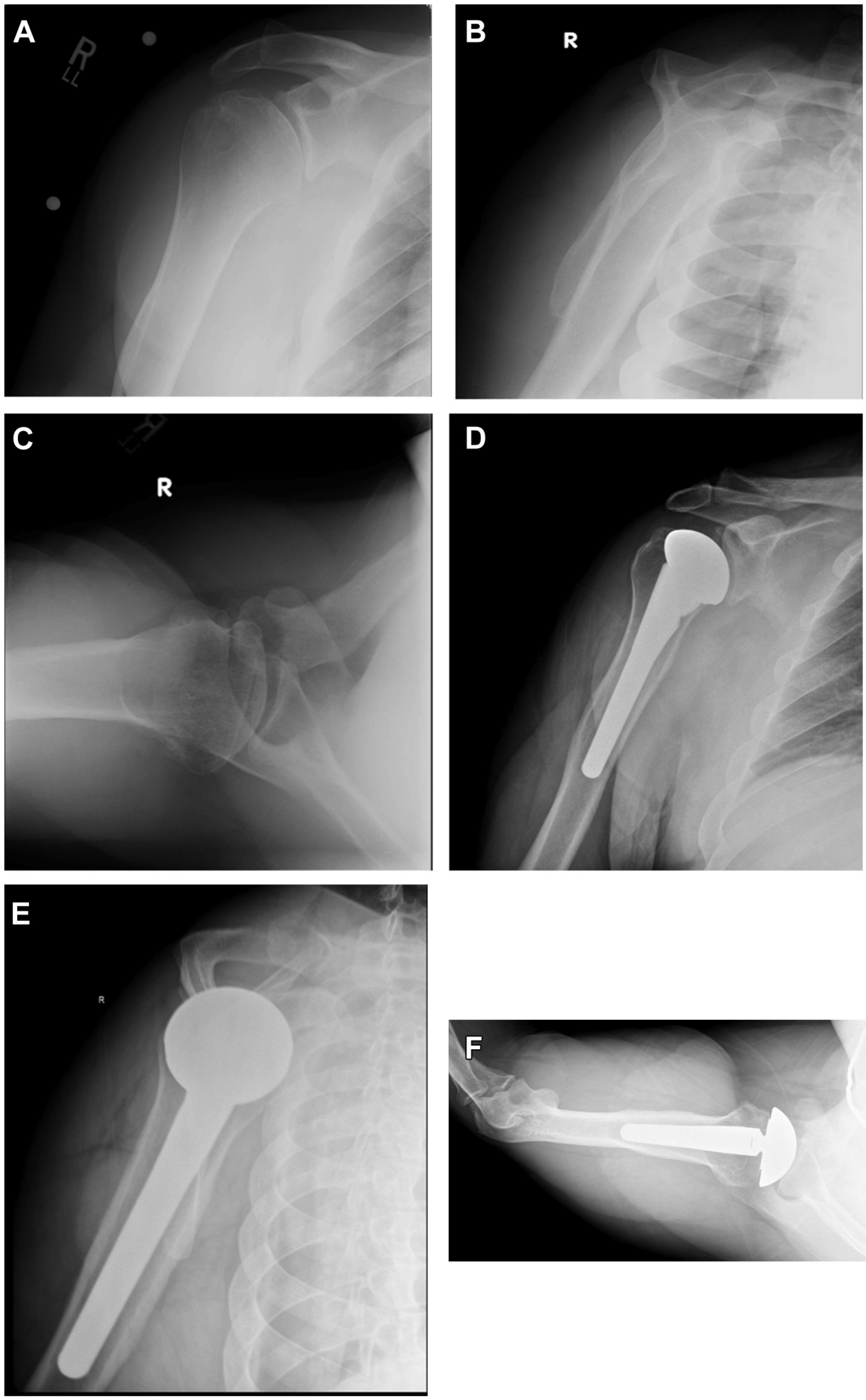

Fig 3. This 36-year-old man, who played high school and collegiate football, presented with progressive shoulder pain. Radiographs were obtained, including (A) Grashey anteroposterior (AP), (B) scapular Y lateral, and (C) axillary lateral views, which showed glenohumeral osteoarthritis. The patient underwent hemiarthroplasty, with subsequent resolution of his pain. Postoperative films at 1 year show a well-fixed and well-aligned prosthesis on (D) Grashey AP, (E) scapular Y lateral, and (F) axillary lateral views.

yielded significant differences, our study is adequately powered. Finally, it should be noted that biologic treatment options were not included in this study.

Conclusions

According to current Level IV data, TSA provides greater improvement of pain and range of motion than does HA in the surgical treatment of young patients with glenohumeral arthritis. AD is an efficacious and particularly safe alternative in the short term for young patients with concerns about arthroplasty.

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Appendix Table 1. Surgical Technique in Included Studies

Study	Treatment	No.	Technique	Surgical Position	Surgical Approach	Concomitant Procedures
Muh (2014)[59]	HA + BR	16	Achilles tendon allograft (9) or ADM (7); standard or resurfacing	BC	DP	NR
Denard (2013)[55]	TSA	50	Glenoid: polyethylene; reaming (25), curettage (25) Humeral: cemented (46), press-fit (4)	NR	DP	Biceps tenotomy or tenodesis (29), subacromial decompression (2), supraspinatus repair (1)
Hammond (2013)[41]	HA	20	NR	BC	DP	NR
	HA + BR	20	Lateral meniscus allograft (12) or ADM (8)	BC	DP	
Merolla (2013)[45]	HA + BR	60	Meniscal allograft (22), ADM (4), NR (34)	BC	DP	Lesser tuberosity osteotomy (60), microfracture (10)
Millett (2013)[46]	AD	28	NR	BC	A	Chondroplasty with global capsular release (30), subacromial bursectomy (30), synovectomy (20), humeral osteoplasty and osteophyte resection (14), subacromial decompression (10), loose body removal, (9), biceps tenodesis (8), axillary nerve neurolysis (7), microfracture (4)
Strauss (2014)[51]	HA + BR	45	Lateral meniscus allograft (31) or ADM (10)	BC	DP	Biceps tenodesis (45), capsulorrhaphy (4), hardware removal (3), glenoid bone grafting (1), Latarjet procedure (1)
Gadea (2012)[56]	HA	229	NR	NR	NR	NR
Levine (2012)[61]	HA	28	Neer II prosthesis	NR	DP	Subacromial decompression (4)
Bartelt (2011)[38]	TSA	46	NR	NR	NR	Glenoid (2) or humeral (1) bone grafting
	HA	20				
Lollino (2011)[12]	HA + BR	18	Lateral meniscus allograft	BC	DP	NR
Saltzman (2011)[15]	R & R	65	NR	NR	NR	NR
de Beer (2010)[54]	HA + BR	32	ADM	LD	A	Arthroscopic debridement with osteophyte and loose body removal and correction of abnormal glenoid biconcavity ± biceps tenotomy (19)
Ohl (2010)[47]	HA	19	Anatomic (6) or resurfacing (13)	BC	DP	Biceps tenodesis (9), transosseous supraspinatus reattachment (3)
Van Thiel (2010)[17]	AD	71	NR	NR	A	Capsular release (44), subacromial decompression (28), biceps tenodesis or tenotomy (14), loose body or osteophyte removal (12), microfracture (11)
Betts (2009)[39]	TSA	14	NR	NR	NR	NR
Elhassan (2009)[16]	HA + BR	13	Achilles tendon allograft (11), fascia lata autograft (1), or anterior capsule (1); anatomic	BC	DP	Biceps tenodesis (13), lesser tuberosity osteotomy (13)
Lee (2009)[42]	HA + BR	18	Anterior capsule; uncemented	NR	NR	NR
McNickle (2009)[44]	HA + BR	8	Lateral meniscus allograft or ADM	NR	NR	NR
	AD	5				
Savoie (2009)[49]	HA + BR	20	ADM	LD	A	NR
Wirth (2009)[53]	HA + BR	27	Lateral meniscus allograft	NR	NR	NR
Bailie (2008)[37]	HA	36	Uncemented	NR	DP	Biceps tenodesis (36), chondral debridement (18), RCR (4), glenoid bone grafting (3), microfracture (2), lateral meniscal allograft for posterior instability and deficient labrum (1)
Levy (2008)[43]	TSA	11	NR	NR	NR	NR
Raiss (2008)[48]	TSA	21	Anatomic; cemented	NR	DP	NR

(continued)

Appendix Table 1. Continued

Study	Treatment	No.	Technique	Surgical Position	Surgical Approach	Concomitant Procedures
Johnson (2007)[57]	HA + BR	16	Lateral meniscus allograft; anatomic	NR	DP	NR
Krishnan (2007)[10]	HA + BR	36	Achilles tendon allograft (18) fascia lata autograft (11), or anterior capsule (7); uncemented (26) or cemented (10)	BC	DP	NR
Nicholson (2007)[14]	HA + BR	30	Lateral meniscus allograft; metallic	NR	DP	Biceps tenodesis (30), subscapularis lengthening (6)
Richards (2007)[60]	AD	8	NR	LD	NR	Capsular release ± subacromial decompression
Burroughs (2003)[40]	HA TSA	16 4	NR	NR	NR	NR
Sperling (2002)[50]	HA (10) TSA (21)	31	Glenoid: Cemented polyethylene (4) or cemented metal backed (2) Humeral: Cemented polyethylene (7) or metal backed (8)	NR	DP (23), AM (8)	Subscapularis z-plasty (7), glenoid bone grafting (4)
Weinstein (2000)[52]	AD	25	NR	BC	A	Loose body removal (3), acromioclavicular resection (2), acromioplasty (2)
Sperling (1998)[31]	HA (74) TSA (34)	108	Humeral: press-fit (70) or cemented (8) Humeral: press-fit (31) or cemented (5) Glenoid: press-fit (31) or cemented (5)	NR	NR	RCR (15), greater tubercle reconstruction (7), humeral (6) or glenoid (2) bone grafting
Burkhead (1995)[13]	HA + BR	6	Fascia lata autograft or anterior capsule; uncemented	BC	Long DP	NR

A, arthroscopic; AD, arthroscopic debridement; ADM, acellular dermal tissue matrix; AM, anteromedial; BC, beach chair; BR, biologic resurfacing; DP, deltopectoral; HA, hemiarthroplasty; LD, lateral decubitus; NR, not reported; RCR, rotator cuff repair; TSA, total shoulder arthroplasty.

Appendix Table 2. Clinical Outcome Scores in Included Studies

Study	Technique	No.	ASES (Pre-operative)	ASES (Post-operative)	UCLA (Pre-operative)	UCLA (Post-operative)	Constant (Pre-operative)	Constant (Post-operative)	SST (Pre-operative)	SST (Post-operative)	SANE (Pre-operative)	SANE (Post-operative)	Neer (Post-operative)	Other (Pre-operative)	Other (Post-operative)
Muh (2014)[59]	HA + BR	16	23.2	57.7	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Denard (2013)[55]	TSA	50	NR	NR	NR	NR	31.6	58.4	NR	NR	NR	NR	NR	NR	SSV: 70
Hammond (2013)[41]	HA	20	26.7	67.0	NR	NR	NR	67.9	3.9	7.5	NR	77.5	NR	NR	NR
	HA + BR	20	NR	59.5	NR	NR	NR	53	NR	6.9	NR	54.5	NR	NR	NR
Merolla (2013)[45]	HA + BR	60	NR	NR	NR	NR	36.2	66.4	3.9	8.2	NR	NR	NR	NR	NR
Millett (2013)[46]	AD	22	58	83	NR	NR	NR	NR	NR	NR	NR	87	NR	NR	DASH: 17
Strauss (2014)[51]	HA + BR	41	36.8	62.0	NR	NR	NR	NR	4.0	7.0	NR	NR	NR	NR	NR
Gadea (2012)[56]	HA	110	NR	NR	NR	NR	28.6	60.8	NR	NR	NR	NR	NR	NR	NR
Levine (2012)[61]	HA	28	NR	70.5	NR	NR	NR	NR	NR	8.2	NR	NR	4 e, 3 g, 3 f, 18 p	NR	NR
Bartelt (2011)[38]	TSA	46	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	HA	20	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Lollino (2011)[12]	HA + BR	18	NR	NR	NR	NR	49.8	66.2	NR	NR	NR	NR	NR	NR	DASH: 24.2
Saltzman (2011)[15]	R & R	56	NR	NR	NR	NR	NR	NR	4.1	9.5	NR	NR	NR	NR	NR
de Beer (2010)[54]	HA + BR	32	NR	NR	NR	NR	40	64.5	NR	NR	NR	NR	9 e, 14 s, 9 u	NR	NR
Ohl (2010)[47]	HA	19	NR	NR	NR	NR	37.4	64.4	NR	NR	NR	NR	NR	NR	SSV: 74.6
Van Thiel (2010)[17]	AD	55	51.8	72.7	NR	28.3	NR	72.0	6.1	9.0	NR	71.1	NR	NR	NR
Betts (2009)[39]	TSA	14	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Elhassan (2009)[16]	HA + BR	13	NR	NR	NR	NR	24	43 (31-73)	NR	NR	NR	NR	NR	SSV: 21	SSV: 33
Lee (2009)[42]	HA + BR	18	NR	74.4	NR	NR	NR	71.4	NR	NR	NR	NR	NR	NR	NR
McNickle (2009)[44]	HA + BR	8	51	71	NR	NR	NR	NR	7	10	NR	NR	NR	NR	NR
	AD	5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Savoie (2009)[49]	HA + BR	20	22	78	15	29	26	79	NR	NR	NR	NR	NR	Rowe: 55	Rowe: 81
Wirth (2009)[53]	HA + BR	27	30	67	NR	NR	NR	NR	2.7	7.3	NR	NR	NR	NR	NR
Bailie (2008)[37]	HA	36	29.8	87.7	NR	NR	NR	NR	NR	NR	24.7	90.4	NR	NR	NR
Levy (2008)[43]	TSA	11	37	77.5	NR	NR	NR	NR	2.8	7.2	NR	NR	NR	NR	NR
Raiss (2008)[48]	TSA	21	NR	NR	NR	NR	24.1	64.5	NR	NR	NR	NR	NR	NR	NR
Johnson (2007)[57]	HA + BR	16	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Krishnan (2007)[10]	HA + BR	36	39	91	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Nicholson (2007)[14]	HA + BR	30	34.8	69	NR	NR	NR	NR	3.3	7.8	NR	NR	NR	NR	NR
Richards (2007)[60]	AD	8	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Burroughs (2003)[40]	HA	16	NR	39.3	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	SPADI: 25.4
	TSA	4	NR	34.0	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	SPADI: 30.8
Sperling (2002)[50]	HA (10)	10	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	4 e, 2 s, 4 u	NR	NR
	TSA (21)	21	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	3 e, 5 s, 13 u	NR	NR
Weinstein (2000)[52]	AD	25	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Sperling (1998)[31]	HA	74	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	15 e, 24 s, 35 u	NR	NR
	TSA	34	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	4 e, 13 s, 17 u	NR	NR
Burkhead (1995)[13]	HA + BR	6	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	5 e, 1 s	NR	NR

AD, arthroscopic debridement; ASES, American Shoulder and Elbow Surgeons; BR, biologic resurfacing; DASH, Disabilities of the Arm, Shoulder, and Hand; HA, hemiarthroplasty; NR, not reported; R & R, ream and run; SANE, Single Assessment Numeric Evaluation; SPADI, Shoulder Pain and Disability Index; SST, Simple Shoulder Test; SSV, subjective shoulder value; TSA, total shoulder arthroplasty; UCLA, University of California, Los Angeles.

Appendix Table 3. Subjective Outcomes in Included Studies

Study	Technique	No.	Pain	Functional Improvement	Satisfaction	Return to Activity	Health-Related Quality of Life
Muh (2014)[59]	HA + BR	16	VAS (preoperative): 8.1 VAS (postoperative): 5.8 9 of 16 improved	NR	NR	NR	NR
Denard (2013)[55]	TSA	50	Constant (preoperative): 3.9 Constant (postoperative): 10.1	NR	34 of 50	NR	NR
Hammond (2013)[41]	HA	20	VAS (preoperative): 5.1 VAS (postoperative): 1.8	NR	NR	NR	NR
	HA + BR	20	VAS (preoperative): NR VAS (postoperative): 4.8	NR	NR	NR	NR
Merolla (2013)[45]	HA + BR	60	VAS (preoperative): 8.16 VAS (postoperative): 2.4	NR	55 of 60	NR	NR
Millett (2013)[46]	AD	22	VAS (preoperative): 3.5 VAS (postoperative): 1.7	NR	Rating = 9 of 10	NR	SF-12-P: Δ 6.6 SF-12-M: Δ 2.6
Strauss (2014)[51]	HA + BR	41	VAS (preoperative): 6.3 VAS (postoperative): 3.0	NR	NR	NR	NR
Gadea (2012)[56]	HA	110	Constant (preoperative): 4.1 Constant (postoperative): 6.6 96 of 110 improved	NR	NR	NR	NR
Levine (2012)[61]	HA	28	NR	NR	Neer rating = 25%	NR	SF-36 (postoperative): 69.7 EuroQol (postoperative): 0.55
Bartelt (2011)[38]	TSA	46	Other: Δ −2.4 of 5	NR	40 of 47	NR	NR
	HA	20	Other: Δ −1.6 of 5	NR	13 of 20	NR	NR
Lollino (2011)[12]	HA + BR	18	12 of 18 improved	15 of 18	15 of 18	NR	NR
Saltzman (2011)[15]	R & R	56	NR	53 of 56	NR	NR	NR
de Beer (2010)[54]	HA + BR	32	VAS (preoperative): 8 VAS (postoperative): 2 23 of 32 improved	23 of 32	NR	NR	NR
Ohl (2010)[47]	HA	19	Constant: Δ 6.3	Constant activity: Δ 5.6, mobility Δ 11.1, strength Δ 4.0	NR	NR	NR
Van Thiel (2010)[17]	AD	55	VAS (preoperative): 4.8 VAS (postoperative): 2.7	NR	NR	NR	SF-12 T: Δ 0.2
Betts (2009)[39]	TSA	14	VAS (preoperative): NR VAS (postoperative): 0.45	NR	NR	NR	NR
Elhassan (2009)[16]	HA + BR	13	VAS (preoperative): 8 VAS (postoperative): 6 2 of 13 improved	NR	NR	NR	NR
Lee (2009)[42]	HA + BR	18	VAS (preoperative): NR VAS (postoperative): 0.5 (rest), 2.4 (activity of work)	17 of 18	15 of 18	NR	NR
McNickle (2009)[44]	HA + BR	8	VAS (preoperative): 5 VAS (postoperative): 3	NR	NR	NR	SF-12 P and SF-12 M not improved
	AD	5	NR	NR	NR	NR	NR
Savoie (2009)[49]	HA + BR	20	VAS (preoperative): 8 VAS (postoperative): 2	NR	15 of 20	NR	SF-12 T: 6 of 8 categories improved SF-12 P: Δ 24 SF-12 M: Δ 13

(continued)

Appendix Table 3. Continued

Study	Technique	No.	Pain	Functional Improvement	Satisfaction	Return to Activity	Health-Related Quality of Life
Wirth (2009)[53]	HA + BR	27	VAS (preoperative): 46.1 of 100 VAS (postoperative): 14.8 of 100	NR	NR	16 of 27 (sport) 27 of 27 (work)	NR
Bailie (2008)[37]	HA	36	VAS (preoperative): 7.5 VAS (postoperative): 1.3 35 of 36 improved	NR	35 of 36	35 of 36	NR
Levy (2008)[43]	TSA	11	ASES: Δ 16.1 9 of 9 improved	9 of 9	10 of 11	NR	NR
Raiss (2008)[48]	TSA	21	Constant: Δ 9.2	NR	20 of 21	11 of 21	NR
Johnson (2007)[57]	HA + BR	16	VAS (preoperative) NR VAS (postoperative): 44 of 100	NR	NR	NR	NR
Krishnan (2007)[10]	HA + BR	36	VAS (preoperative): 7.7 VAS (postoperative): 2.1 31 of 36 improved (22 excellent; 9 good)	NR	31 of 34	29 of 34	NR
Nicholson (2007)[14]	HA + BR	30	VAS (preoperative): 6.4 VAS (postoperative): 2.3	NR	28 of 30	NR	NR
Richards (2007)[60]	AD	8	NR	NR	NR	NR	NR
Burroughs (2003)[40]	HA	16	NR	NR	13 of 16	7 of 11	NR
	TSA	4	NR	NR	4 of 4	NR	NR
Sperling (2002)[50]	HA	10	7 of 10 improved	NR	NR	NR	NR
	TSA	21	14 of 21 improved	NR	NR	NR	NR
Weinstein (2000)[52]	AD	25	19 of 25 improved	21 of 25	23 of 25	7 of 13	NR
Sperling (1998)[31]	HA	74	Other: Δ 2.2 of 5	NR	NR	6 of 6	NR
	TSA	34	Other: Δ 2.6 of 5	NR	NR	NR	NR
Burkhead (1995)[13]	HA + BR	6	6 of 6 improved (5 excellent; 1 good)	NR	NR	NR	NR

AD, arthroscopic debridement; ASES, American Shoulder and Elbow Surgeons; BR, biologic resurfacing; HA, hemiarthroplasty; M, mental component; P, physical component; R & R, ream and run; SF-12, 12-Item Short Form Health Survey; SF-36, 36-Item Short Form Health Survey; T, total; TSA, total shoulder arthroplasty; VAS, visual analog scale.

Appendix Table 4. Objective Outcomes in Included Studies

Study	Technique	No.	Forward Flexion, ° Δ	Abduction, °	External Rotation, °	Internal Rotation, ° Δ	Overall Complications	Need for Revision	Time to Revision, yr
Muh (2014)[59]	HA + BR	16	Preoperative: 128.1 Postoperative: 134.4	NR	Preoperative: 27.5 Postoperative: 31.6	Preoperative: L4 Postoperative: L4	NR	7 of 16	3.0
Denard (2013)[55]	TSA	50	Preoperative: 97 Postoperative: 128	NR	Preoperative: 12 (adduction) Postoperative: 33 (adduction)	NR	17 of 50	17 of 50	7.4
Hammond (2013)[41]	HA	15	Preoperative: 116 Postoperative: 130	NR	Preoperative: 33 (abduction) Postoperative: 71 (abduction), 48 (adduction)	Preoperative: 35 (abduction) Postoperative: 46 (abduction)	NR	3 of 20	3.9
	HA + BR	17	Preoperative: 119 Postoperative: 123	NR	Preoperative: 28 (abduction) Postoperative: 51 (abduction), 52 (adduction)	Preoperative: 32 (abduction) Postoperative: 38 (abduction)	NR	6 of 20	2.0
Merolla (2013)[45]	HA + BR	60	Preoperative: 90 Postoperative: 135	NR	Preoperative: 10 Postoperative: 50	Preoperative: 15 Postoperative: 45	NR	5 of 60	NR
Millett (2013)[46]	AD	22	Preoperative: 98.2 Postoperative: 152.9	NR	Preoperative: 27.3 (abduction), 13.4 (adduction) Postoperative: 75.4 (abduction), 62.2 (adduction)	Preoperative: 23.8 Postoperative: 60.8	0 of 28	6 of 28	1.9
Strauss (2014)[51]	HA + BR	33	Preoperative: 106 Postoperative: 138	NR	Preoperative: 31 (adduction) Postoperative: 51 (adduction)	NR	5 of 45	8 of 45	NR
Gadea (2012)[56]	HA	229	NR	NR	NR	NR	34 of 229	23 of 141	NR
Levine (2012)[61]	HA	28	Preoperative: 104 Postoperative: 141.8	NR	Preoperative: 20.7 (abduction) Postoperative: 61.0 (abduction)	Postoperative: L5	NR	8 of 28	NR
Bartelt (2011)[38]	TSA	46	Preoperative: 105 Postoperative: 151	NR	Preoperative: 23 Postoperative: 48	Preoperative: sacrum Postoperative: L4	8 of 46	3 of 46	10.9
	HA	20	Preoperative: 103 Postoperative: 114	NR	Preoperative: 23 Postoperative: 38	Preoperative: sacrum Postoperative: L5	3 of 20	6 of 20	3.9
Lollino (2011)[12]	HA + BR	18	NR	NR	NR	NR	2 of 18	NR	NR
Saltzman (2011)[15]	R & R	65	NR	NR	NR	NR	NR	9 of 65	NR
de Beer (2010)[54]	HA + BR	32	Preoperative: 120 Postoperative: 140	Preoperative: 90 Postoperative: 120	Preoperative: 30 Postoperative: 50	Preoperative: 30 Postoperative: 40	5 of 32	5 of 32	0.6
Ohl (2010)[47]	HA	19	NR	Preoperative: 90 Postoperative: 121	Preoperative: 30 Postoperative: 46	Preoperative: Deficit in 16 of 19 Postoperative: Deficit in 13 of 19	2 of 19	NR	NR
Van Thiel (2010)[17]	AD	55	Preoperative: 137 Postoperative: 157	Preoperative: 129 Postoperative: 145	Preoperative: 48 (adduction) Postoperative: 63 (adduction)	NR	NR	16 of 71	0.84
Betts (2009)[39]	TSA	14	NR	Preoperative: 45 Postoperative: 60	Preoperative: 5 Postoperative: 25	Preoperative: buttock Postoperative: buttock	5 of 14	5 of 14	NR
Elhassan (2009)[16]	HA + BR	13	NR	NR	NR	NR	6 of 13	10 of 13	1.17
Lee (2009)[42]	HA + BR	18	Preoperative: NR Postoperative: 130	Preoperative: NR Postoperative: 122	Preoperative: NR Postoperative: 39 (adduction)	NR	2 of 18	NR (≥ 1)	NR
McNickle (2009)[44]	HA + BR	8	Preoperative: 132 Postoperative: 133	NR	Preoperative: 50 (adduction) Postoperative: 42 (adduction)	Preoperative: T12 (adduction) Postoperative: T12 (adduction)	NR	2 of 8	NR
	AD	5	Preoperative: 88 Postoperative: 127	NR	Preoperative: 11 (adduction) Postoperative: 40 (adduction)	Preoperative: buttock (adduction) Postoperative: L1 (adduction)	NR	NR	NR

(continued)

Appendix Table 4. Continued

Study	Technique	No.	Forward Flexion, ° Δ	Abduction, °	External Rotation, °	Internal Rotation, ° Δ	Overall Complications	Need for Revision	Time to Revision, yr
Savoie (2009)[49]	HA + BR	20	Preoperative: 80 Postoperative: 150	Preoperative: 60 Postoperative: 120	Preoperative: 30 (abduction), 10 (adduction) Postoperative: 70 (abduction), 30 (adduction)	Preoperative: 10 (abduction) Postoperative: 50 (abduction)	NR	5 of 20	1-5
Wirth (2009)[53]	HA + BR	27	Preoperative: 83.7 Postoperative: 122.8	NR	Preoperative: 8.9 (adduction) Postoperative: 38.5 (adduction)	Preoperative: 2.1 vertebrae Postoperative: 4.3 vertebrae	3 of 27	5 of 27	0.32
Bailie (2008)[37]	HA	36	NR	NR	NR	NR	5 of 46	4 of 36	2
Levy (2008)[43]	TSA	11	Preoperative: 110 Postoperative: 126	Preoperative: 89 Postoperative: 123	Preoperative: 26 (adduction) Postoperative: 48 (adduction)	NR	NR	1 of 11	NR
Raiss (2008)[48]	TSA	21	Preoperative: 77.9 Postoperative: 128.6	Preoperative: 60.5 Postoperative: 111.2	Preoperative: −2.4 Postoperative: 30.5	Preoperative: 1.1 vertebrae Postoperative: 5.0 vertebrae	1 of 21	0 of 21	NR
Johnson (2007)[57]	HA + BR	16	Preoperative: NR Postoperative: 102	NR	Preoperative: NR Postoperative: 29	NR	NR	10 of 16	NR
Krishnan (2007)[10]	HA + BR	36	Preoperative: 70 Postoperative: 140	NR	Preoperative: 5 Postoperative: 50	Preoperative: SI joint Postoperative: T12	7 of 36	4 of 36	3.3
Nicholson (2007)[14]	HA + BR	30	Preoperative: 96 Postoperative: 139	NR	Preoperative: 26 Postoperative: 53	NR	5 of 30	5 of 30	NR
Richards (2007)[60]	AD	8	Preoperative: 131.9 Postoperative: 153.3	NR	Preoperative: 42.8 Postoperative: 59.4	Preoperative: 17.2 Postoperative: 48.3	NR	NR	NR
Burroughs (2003)[40]	HA	16	NR	NR	NR	NR	NR	2 of 16	1.25
	TSA	4	NR	NR	NR	NR	NR	NR	NR
Sperling (2002)[50]	HA	10	NR	Preoperative: 94* Postoperative: 14*	Preoperative: 4* Postoperative: 43*	NR	5 of 10	3 of 10	6.67
	TSA	21	NR	Preoperative: 94* Postoperative: 141*	Preoperative: 4* Postoperative: 43*	NR	NR	8 of 21	NR
Weinstein (2000)[52]	AD	25	Preoperative: NR Postoperative: 167	NR	Preoperative: NR Postoperative: 53	Preoperative: NR Postoperative: L5	0 of 25	3 of 25	NR
Sperling (1998)[31]	HA	74	NR	Preoperative: 80 Postoperative: 124	Preoperative: 20 Postoperative: 46	Preoperative: L4 Postoperative: L2	4 of 78	15 of 78	7.8
	TSA	34	NR	Preoperative: 62 Postoperative: 104	Preoperative: 17 Postoperative: 43	Preoperative: L4 Postoperative: L3	NR	4 of 36	NR
Burkhead (1995)[13]	HA + BR	6	Preoperative: 81 Postoperative: 138	NR	Preoperative: 5 (abduction) Postoperative: 50 (abduction)	Preoperative: SI joint Postoperative: T12	1 of 6	1 of 6	NR

AD, arthroscopic debridement; BR, biologic resurfacing; HA, hemiarthroplasty; NR, not reported; R & R, ream and run; SI, sacroiliac; TSA, total shoulder arthroplasty.
*Indicates that data were reported for the entire study sample but not for individual treatment groups.

Appendix Table 5. Radiological Outcomes in Included Studies

Study	Technique	No.	Periprosthetic Lucency	Glenoid Erosion	Joint Space	Humeral Head Migration	Radiolucent Lines	Implant Loosening or Malalignment	Glenoid Morphologic Classification (n)	Subluxation
Muh (2014)[59]	HA + BR	16	NR	NR	NR	NR	NR	NR	NR	NR
Denard (2013)[55]	TSA	50	NR	NR	NR	NR	NR	12 of 50	NR	NR
Hammond (2013)[41]	HA	12	NR	NR	NR	NR	NR	NR	NR	NR
	HA + BR	14	NR	NR	< 1 mm in 6 of 13	NR	NR	NR	NR	NR
Merolla (2013)[45]	HA + BR	60	NR	7 of 60	3.21 mm	NR	4 of 60	0 of 60	A1 (40), A2 (11), B1 (9)	NR
Millett (2013)	AD	28	NR	NR	NR	NR	NR	NR	NR	NR
Strauss (2014)[51]	HA + BR	35	NR	NR	0.54 mm	NR	NR	NR	NR	NR
Gadea (2012)[56]	HA	229	NR	NR	NR	NR	NR	NR	NR	NR
Levine (2012)[61]	HA	28	NR	NR	NR	NR	NR	NR	NR	NR
Bartelt (2011)[38]	TSA	34	Humeral: 9 of 34 Glenoid: 21 of 34	NR	NR	NR	NR	NR	A (12), B1 (12), B2 (9), C (1)	17 of 34
	HA	13	3/13	13 of 13	NR	NR	NR	NR	A (8), B1 (2), C (1)	7 of 13
Lollino (2011)[12]	HA + BR	9	NR	NR	2.07 mm	NR	NR	NR	NR	NR
Saltzman (2011)[15]	R & R	22	NR	NR	1.0 mm	NR	NR	NR	NR	NR
de Beer (2010)[54]	HA + BR	22	NR	NR	Intact in 12 of 22	NR	NR	NR	NR	NR
Ohl (2010)[47]	HA	19	NR	11 of 19	1.92 mm	3.80 mm	NR	NR	NR	6 of 19
Van Thiel (2010)[17]	AD	46	NR	NR	2.35 mm	NR	NR	NR	NR	NR
Betts (2009)[39]	TSA	14	NR	NR	NR	14 of 14	12 of 14	11 of 14	NR	NR
Elhassan (2009)[16]	HA + BR	13	NR	NR	NR	NR	NR	NR	NR	NR
Lee (2009)[42]	HA + BR	16	NR	NR	0.13 mm	0 of 16	0 of 16	0 of 16	NR	4 of 16
McNickle (2009)[44]	HA + BR	8	NR	NR	NR	NR	NR	NR	NR	NR
	AD	5	NR	NR	NR	NR	NR	NR	NR	NR
Savoie (2009)[49]	HA + BR	20	NR	NR	Intact in 20 of 20	NR	NR	NR	NR	NR
Wirth (2009)[53]	HA + BR	27	NR	0 of 27	1.7 mm	NR	NR	NR	NR	1 of 27
Bailie (2008)[37]	HA	36	NR	NR	NR	NR	NR	0 of 36	A1 (26), A2 (2), B1 (8)	Minimal
Levy (2008)[43]	TSA	11	NR	NR	NR	NR	0 of 11	NR	NR	2 of 11
Raiss (2008)[48]	TSA	21	NR	NR	NR	2 of 21	10 of 21	0 of 21	A2 (3), B1 (9), B2 (7), C (2)	NR
Johnson (2007)[57]	HA + BR	16	NR	NR	NR	NR	NR	NR	NR	NR
Krishnan (2007)[10]	HA + BR	36	NR	NR	1.3 mm	NR	0 of 36	0 of 36	NR	NR
Nicholson (2007)[14]	HA + BR	30	NR	0	1.8 mm	NR	NR	NR	NR	0 of 30
Richards (2007)[60]	AD	8	NR	NR	NR	NR	NR	NR	NR	NR
Burroughs (2003)[40]	HA	11	NR	1 of 10	NR	NR	1 of 10	1 of 10	NR	NR
	TSA	4	NR	NR	NR	NR	2 of 2	2 of 2	NR	NR
Sperling (2002)[50]	HA	9	7 of 9	7 of 9	NR	NR	NR	NR	NR	5 of 9
	TSA	18	Humeral: 9/18 Glenoid: 9/18	NR	NR	NR	NR	NR	NR	2 of 18
Weinstein (2000)[52]	AD	25	NR	NR	NR	NR	NR	NR	NR	NR
Sperling (1998)[31]	HA	68	NR	46 of 68	Cartilage loss in 57 of 68	NR	16 of 68	NR	NR	30 of 68
	TSA	32	NR	NR	NR	NR	Humeral: 17 of 32 Glenoid: 19 of 32	NR	NR	NR
Burkhead (1995)[13]	HA + BR	6	0/6	0	0.5-3.0 mm	NR	NR	NR	NR	NR

AD, arthroscopic debridement; BR, biologic resurfacing; HA, hemiarthroplasty; NR, not reported; R & R, ream and run; TSA, total shoulder arthroplasty.