J Shoulder Elbow Surg (2019) 28, e359–e376

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

ONLINE ARTICLES

Risk of poor outcomes in patients who are obese following total shoulder arthroplasty and reverse total shoulder arthroplasty: a systematic review and meta-analysis

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Background: A systematic review was performed to investigate the impact of obesity on outcomes following total shoulder arthroplasty (TSA) and reverse total shoulder arthroplasty (RTSA).
Methods: Electronic databases and the grey literature were searched for studies that evaluated the influence of obesity (body mass index $\geq$ 30 kg/m^2) on TSA and RTSA outcomes. A total of 15 studies were identified, with 10 studies reporting on predetermined outcomes considered in the TSA and RTSA population. Unadjusted data were pooled in a statistical meta-analysis where appropriate (Review Manager [RevMan], version 5.3) or summarized in narrative form. Effect sizes were expressed as odds ratios (ORs) for categorical data and weighted mean differences (WMDs) for continuous data.
Results: The findings suggested that patients who were obese were at increased odds of a dislocation (OR, 2.49; 95% confidence interval [CI], 2.32-2.66), fracture (OR, 1.92; 95% CI, 1.77-2.08), and revision (OR, 1.49; 95% CI, 1.40-1.58) following TSA or RTSA. Conversely, obesity had no influence on the odds of an unscheduled return to the operating theater (OR, 0.83; 95% CI, 0.43-1.61). Postoperative forward flexion in patients who were obese differed from that in patients who were not obese (WMD, –9.8°; 95% CI, –17.53° to –2.07°); however, no differences in other functional measures including abduction (WMD, –0.78; 95% CI, –7.27 to 5.71) and external rotation (WMD, –1.41; 95% CI, –5.11 to 2.29) were found. Although patients who were obese reported significantly higher levels of pain (WMD, 1.13; 95% CI, 0.21 to 2.06), the difference was not clinically relevant.
Conclusions: Surgeons should consider advising patients who are obese of the greater risk of dislocation, fracture, and revision when considering elective TSA or RTSA. Findings are limited by confounding variables but further our understanding of additional risks associated with pre-existing obesity, which will promote better-informed decisions prior to proceeding with surgery.

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

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https://doi.org/10.1016/j.jse.2019.06.017

Level of evidence: Level III; Systematic Review and Meta-analysis

Keywords: Obesity; BMI; outcomes; upper-limb arthroplasty; total shoulder arthroplasty; dislocation

Total shoulder arthroplasty (TSA) and reverse total shoulder arthroplasty (RTSA) are effective treatments commonly used in the medical care of elderly populations. With advancing age comes a greater risk of further chronic conditions, such as obesity, increasing the likelihood of comorbid patients presenting for elective arthroplasty. Obesity is common in older populations across Australia,[2] England,[10] and many other countries,[37] yet the available evidence on the impact of obesity on upper-limb arthroplasty outcomes is inconsistent.[44]

Pain and poor joint function detrimentally impact quality of life (QoL) and are primary symptoms leading to total joint replacement. Shoulder pain for 3 months or greater has been linked to depression, anxiety, and sleep disturbance.[8] Research has shown significant improvements in pain, function, and psychological status following arthroplasty.[9] In a general population, obesity has been association with decreased shoulder function.[28] Furthermore, increasing body mass index (BMI) is correlated with the incidence and severity of rotator cuff tears, a common indication for shoulder arthroplasty.[18]

Arthroplasty patients can return to the operating theater for numerous reasons, such as for irrigation and débridement or revision surgery. Revision arthroplasty is a complex procedure with a greater risk of complications and poorer outcomes than primary arthroplasty.[14,49] Instability and dislocation combined is identified as the most common cause of prosthesis revision following TSA and RTSA, accounting for 25.2% and 38.5% of TSA and RTSA revisions, respectively, in Australia.[3]

An understanding of the relationship between pre-existing obesity and arthroplasty outcomes is essential as it may impact patient selection for different types of orthopedic surgery. Patients must be better informed of any additional risks associated with a pre-existing chronic disease, as this may influence their decision making. Orthopedic surgeons may also consider alternate treatments or further precautionary measures to ensure the safety and effectiveness of the arthroplasty procedure in patients identified at greater risk of poorer outcomes.

To date, research has considered a number of perioperative, short- and longer-term outcomes for patients with comorbid conditions in isolation. A literature search identified a review that investigated the effect of obesity on TSA; however, the authors did not address the question through a systematic review or meta-analysis.[11]

To develop a clear understanding of the impact of obesity on upper-limb arthroplasty outcomes, we performed a systematic review to address the following questions: (1) Are obese patients at an increased risk of a dislocation, fracture, unscheduled return to the operating theater, or revision following TSA or RTSA? (2) Are obese patients at an increased risk of poorer function, pain relief, and QoL following TSA or RTSA?

Materials and methods

This review was conducted in accordance with an a priori protocol of a larger review project investigating additional complications and the influence of diabetes mellitus on upper-limb arthroplasty outcomes.[44] Specific outcomes of the shoulder arthroplasty population are reported in the current article. This review was prospectively registered on PROSPERO (CRD42016053299).

Search strategy and criteria

A comprehensive 3-step search strategy was undertaken across the PubMed, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and Embase databases on May 27, 2016, with no limitation on publication date. Articles in languages other than English were excluded. The grey-literature search included a review of relevant conference proceedings and the OpenGrey database. Detailed search strategies are available in Supplementary Appendix S1. The reference lists of all eligible studies were screened for additional studies.

Inclusion and exclusion criteria

Adults, aged 18 years or older, who had undergone primary upper-limb arthroplasty were considered for inclusion. When the impact of obesity was considered for a combination of arthroplasty procedures including those on the lower limb, the study authors were contacted for specific data on the cohort of interest. If the data were not available or a response was not received, the study was deemed eligible for inclusion if it included at least 70% of the population of interest (upper-limb arthroplasty).

Eligible studies must have investigated the impact of obesity (BMI $\geq$ 30.0 kg/m^2) on outcomes in isolation. The term "non-obese" has been used to describe patients categorized with a BMI of less than 30.0 kg/m^2. The "obese" category was further subdivided into "obese class 1" (BMI of 30.0-34.9 kg/m^2) and "obese class 2" (BMI $\geq$ 35.0 kg/m^2), depending on the BMI groups reported in the primary studies. "Morbidly obese" indicated a BMI of 40.0 kg/m^2 or greater, and BMI in the "normal range" referred to patients with a BMI of less than 25.0 kg/m^2.

The review considered cohort and case-control studies for inclusion. Studies reporting on one or more of the following outcomes in the TSA or RTSA population are discussed in this review: dislocation, fracture, function, QoL, pain, unscheduled return to the operating theater, and revision.

Assessment of methodologic quality

The methodologic validity of included studies was assessed by two independent reviewers (A.T. and a non-author) using standardized critical appraisal tools (System for the Unified Management, Assessment and Review of Information [SUMARI]; The Joanna Briggs Institute, Adelaide, SA, Australia).[42,43] Appraisal was piloted with a subset of studies to determine suitability and consistency in understanding of the application of the tools for each reviewer. No disagreements arose; therefore, consultation with a third reviewer (E.A.) was not required. However, assessments of appraisal questions relating to outcomes (ie, questions 6, 7, and 8 for cohort study design and question 8 for case-control study design; Table 1) were re-evaluated by a single reviewer (A.T.). This allowed assessment to be limited to those outcomes presented in this review and differed from those assessments relevant to remaining outcomes from the larger review project.[44] All eligible studies were included in the review irrespective of their methodologic quality.

Data extraction

Data were extracted from included studies using a customized data extraction template (A.T.). Prior to analysis, all extracted data were checked with source articles to confirm accuracy.

When possible, unadjusted data (number of events) were extracted and used in most of the meta-analyses for multiple reasons. The first reason was to avoid potential heterogeneity attributable to adjustment for different confounding factors between studies.[46] The second was that BMI groupings varied between the included studies. The use of unadjusted data permitted the combination of BMI categories that aligned with classifications used in this review. Consequently, for all outcomes, we aimed to conduct a single, overall meta-analysis comparing patients who were obese vs. non-obese. For categorical variables, event and sample totals were summed for each BMI group: BMI of less than 30.0 kg/m^2 vs. BMI of 30.0 kg/m^2 or greater. Conversely, for continuous variables, BMI groupings within a study could not be summed; consequently, multiple meta-analyses comparing various BMI groupings were conducted. When various BMI categories did not align across studies, outcomes were combined in the overall meta-analysis comparing patients who were obese vs. non-obese, despite variations in individual study BMI groupings. For example, Pappou et al[35] categorized BMI of 40.0 kg/m^2 or greater, not specifically greater than 30.0 kg/m^2. The aforementioned approach was necessary for meta-analyses conducted for outcomes including dislocation, revision, pain, and function. Furthermore, when possible, multiple meta-analyses using the various BMI categories were conducted for each outcome, allowing exploration of the impact of different levels of BMI on outcome.

Jiang et al[27] simply reported the percentage of outcome events, without reporting the raw number of events. As raw figures were

Table I Assessment of methodologic quality

Included study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
Cohort study design											
Jiang et al[27]	Y	Y	N	Y	Y	NA	Y	Y	NA	NA	Y
Werner et al[50]	Y	Y	N	Y	N	NA	U	Y	NA	NA	N
Gupta et al[19]	N	Y	N	Y	Y	NA	Y	Y	NA	NA	Y
Chalmers et al[6]	Y	Y	N	Y	Y	NA	Y	Y	NA	NA	Y
Li et al[30]	Y	Y	N	Y	N	NA	U	Y	U	U	N
Mau et al[34]	N	Y	N	N	N	NA	U	Y	NA	NA	N
Beck et al[4]	Y	Y	N	Y	Y	NA	Y	Y	NA	NA	Y
Singh et al[39]	Y	Y	Y	Y	Y	NA	Y	Y	NA	NA	Y
Singh et al[40]	Y	Y	N	Y	Y	NA	Y	Y	NA	NA	Y
Total with Y score, %	77.8	100.0	11.1	88.9	66.7	0.0	66.7	100.0	0.0	0.0	66.7
Total with N score, %	22.2	0.0	88.9	11.1	33.3	0.0	0.0	0.0	0.0	0.0	33.3
Total with U score, %	0.0	0.0	0.0	9.1	0.0	0.0	33.3	0.0	11.1	11.1	0.0
Total with NA score, %	0.0	0.0	0.0	0.0	0.0	100	0.0	0.0	88.9	88.9	0.0
Case-control study design											
Pappou et al[35]	Y	Y	Y	N	Y	Y	NA	Y	Y	Y	—

Q, question; *Y*, yes; *N*, no; *NA*, not applicable; *U*, unclear.
The total columns contain the percentage of cohort studies graded as yes, no, unclear, or not applicable for each critical appraisal question. Cohort and case-control studies are reported separately. The appraisal questions for cohort studies were as follows: (1) Were the groups similar and recruited from the same population? (2) Were the variables (exposures and/or outcomes) measured similarly to assign people to both exposed and unexposed groups? (3) Was the exposure and/or outcome used to group participants measured in a valid and reliable way? (4) Were confounding factors identified? (5) Were strategies to deal with confounding factors stated? (6) Were the groups and/or participants free of the outcome at the start of the study (or at the moment of exposure)? (7) Were the outcomes measured in a valid and reliable way? (8) Was the follow-up time reported and sufficient to be long enough for outcomes to occur? (9) Was follow-up complete, and if not, were the reasons for loss to follow-up described and explored? (10) Were strategies to address incomplete follow-up used? (11) Was appropriate statistical analysis used? The appraisal questions for case-control studies were as follows: (1) Were the groups comparable other than the presence of disease in cases or the absence of disease in controls? (2) Were cases and controls matched appropriately? (3) Were the same criteria used for identification of cases and controls? (4) Was exposure measured in a standard, valid, and reliable way? (5) Was exposure measured in the same way for cases and controls? (6) Were confounding factors identified? (7) Were strategies to deal with confounding factors stated? (8) Were outcomes assessed in a standard, valid, and reliable way for cases? (9) Was the exposure period of interest long enough to be meaningful? (10) Was appropriate statistical analysis used?

required for meta-analysis, they were calculated, when possible, from the data available. As the study reported on a large database, this created a potential for error in the calculation.

Data analysis

Quantitative data, when possible, were pooled in a statistical meta-analysis using Review Manager (RevMan) software (version 5.3; The Cochrane Collaboration, London, UK).[36] Effect sizes with 95% confidence intervals (CIs) were expressed as odds ratios (ORs) for categorical data and weighted mean differences (WMDs) for continuous data. A random-effects model with a Mantel-Haenszel statistical method for ORs[20] and an inverse variance method for WMDs was used for the meta-analyses.[21] When five or fewer studies were included in the analysis, a fixed-effects model was preferentially used.[24] Statistical heterogeneity was assessed using both the standard χ^2 and I^2. When possible, a sensitivity analysis was conducted for meta-analyses heavily weighted with the findings of a single study (>90.0%). For outcomes for which statistical pooling was not possible, the findings are presented in narrative form.

Results

Search and study selection

Database searching returned 9596 citations, which were transferred to EndNote X7 (Clarivate Analytics, Philadelphia, PA, USA). A further 793 records were identified from grey-literature sources (Fig. 1). Following removal of duplicates, 7203 original records were screened for eligibility by one reviewer (A.T.). The full text of 260 studies was retrieved for further assessment of eligibility; of these studies, 229 were excluded (Fig. 1). An additional 17 citations were identified via reference list screening of eligible studies. Eight records were excluded because of insufficient information to determine eligibility following unsuccessful document retrieval requests as well as requests for further information made to the study authors.[12,15,17,22,23,25,32,33] A total of 23 eligible studies were identified; however, two could not be included in our synthesis because of an overlapping patient population selected from the same national database.[16,49] An eligible study that reported on the same patient cohort was preferentially selected when the study provided the greatest representation, with the most recent or readily extractable data. In cases where a study with an overlapping cohort provided additional outcomes, this study was included but only data on the additional outcomes were extracted. Following a breakdown by exposure, eight studies investigated diabetes mellitus alone and are to be discussed in a separate article. A total of 15 obesity studies were identified, with 10 studies reporting on specific outcomes (as discussed in the "Materials and methods" section) considered in the TSA or RTSA population.[4,6,19,27,30,34,35,39,40,50]

A total of 152,306 patients were reported on across the included studies, most of whom were women (61%; 93,067 female patients) and mostly patients aged 65 years or older. Four studies reported on whether the obese cohort had a diabetic comorbidity.[4,19,27,50] The follow-up duration varied across studies and outcomes and ranged from "up to 30 days" to "up to 20 years" (Table II).

Methodologic quality of included studies

A summary of the characteristics of the included studies is presented in Table II. Study designs included eight retrospective cohort studies,[4,6,19,27,34,39,40,50] one prospective cohort study,[30] and one case-control study.[35] All studies were conducted in the United States. Most studies retrospectively gathered data from national or multi-institutional health care and/or surgical databases (Table II).

The majority of cohort studies (78%) recruited participant groups from the same population, and all measured outcomes and/or exposures similarly to assign study groups (Table I). However, only one study (11%) measured the outcome or exposure used to group participants in a valid and reliable way. Most studies (90%) identified key confounders, specifically age, sex, or comorbidities; however, strategies to deal with such factors were not reported in all studies (67%). Whether the groups were free of the outcomes at the start of the study was not applicable for all studies because the outcomes are not relevant preoperatively. Outcomes were measured in a valid and reliable way in 67% of studies; however, this was unclear in 33% of studies. Completion of follow-up was not applicable given the retrospective nature of most studies. Appropriate statistical methods were reported by most studies (67%).

The case-control study matched controls, at minimum, on age, sex, surgical procedure, and duration of follow-up, with data for matching collected from the same source population.[35] Equivalent criteria were used for identification of cases and controls, and confounding variables were identified. The exposures were measured in the same way for each group (eg, level of obesity was measured by BMI for both groups); however, a description on how the exposure was measured was not reported (eg, methods and/or equipment used to measure height and weight for BMI calculations). A description of how outcomes were assessed or diagnosed was provided, and both the length of follow-up and statistical analysis were appropriate (Table I).

Effect of obesity on dislocation, fracture, unscheduled return to operating theater, and revision

Three TSA and/or RTSA studies evaluated the influence of obesity on joint dislocation.[6,19,50] One of the studies did not contribute to the effect estimate as it reported no dislocations for both the obese and non-obese BMI groups.[6] The postoperative follow-up duration varied with each study

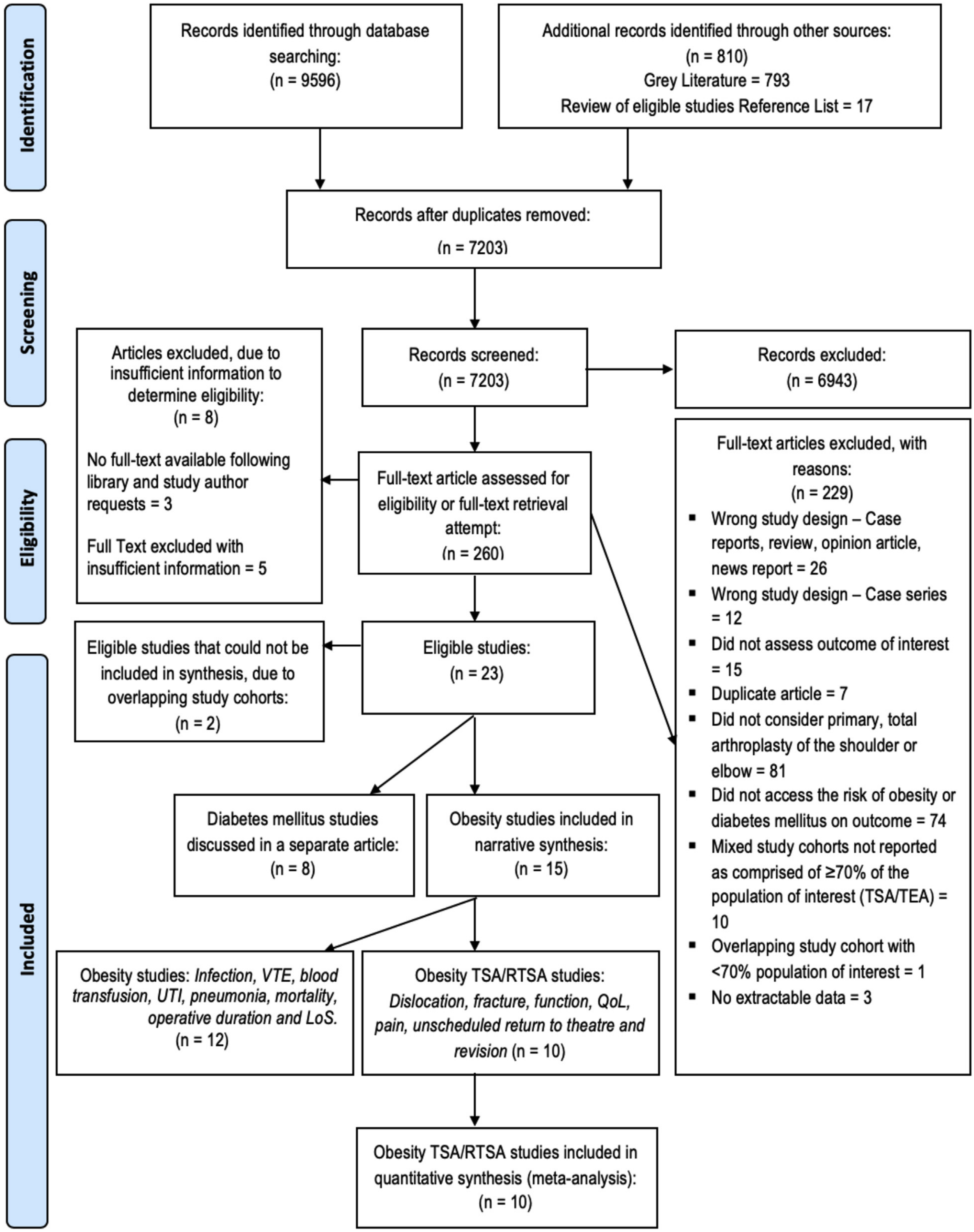

Figure 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flow diagram outlining process of study selection and inclusion. It should be noted that 2 studies reported on both obesity and diabetes mellitus, that is, a total of 21 unique studies were identified prior to breakdown by exposure. *TEA*, total elbow arthroplasty; *TSA*, total shoulder arthroplasty; *VTE*, venous thromboembolism; *UTI*, urinary tract infection; *LoS*, length of stay; *RTSA*, reverse total shoulder arthroplasty; *QoL*, quality of life.

Table II Summary of characteristics of included studies

Included study	Methods	Exposure and arthroplasty procedure	Participants/Patients	Setting and exclusions	Complications and postop outcomes
Jiang et al[27]	Study design: retrospective cohort study Follow-up: up to 30 d Country of origin: USA No. of surgeons performing procedure: not reported Surgical technique: not reported	Exposure 1. BMI of 18.5-25 2. BMI of 25-30 3. BMI of 30-35 4. BMI > 35 Procedure: TSA and RTSA Indication for procedure: not reported	Sample size Total N = 4267 1. n = 738 2. n = 1463 3. n = 1126 4. n = 940 Demographic characteristics Age, average (SD), yr 1. 72 (11) 2. 71 (10) 3. 69 (10) 4. 67 (9) Sex, n 1. 494 F/244 M 2. 717 F/746 M 3. 574 F/552 M 4. 583 F/357 M Ethnicity/nationality, % White/Hispanic 1. 86 2. 85 3. 89 4. 94 Black 1. 3 2. 3 3. 3 4. 7 Asian 1. 2 2. <1 3. <1 4. <1 DM comorbidity, n (%) 1. 59.0 (8) 2. 175.6 (12) 3. 132.8 (18) 4. 253.8 (27)	Setting: The American College of Surgeons National Surgical Quality Improvement Program database was analyzed from 2006 to 2013 for all patients who underwent a primary TSA, including anatomic TSA and RTSA. Exclusions: Patients were excluded if they had a BMI < 18.5; lacked documented preop height and weight; or had previous shoulder hardware, fracture, pathologic fracture, tumor, or associated infection.	Return to operating theater, n (%) (unknown causes) 1. 10.3 (1.4) 2. 8.8 (0.6) 3. 7.9 (0.7) 4. 6.6 (0.7) Adjusted RR (95% CI); *P* value 2. 0.29 (0.07-1.29); .103 3. 0.56 (0.14-2.23); .408 4. 0.58 (0.12-2.89); .504
Werner et al[50]	Study design: retrospective cohort study	Exposure 1. Non-obese (BMI < 30)	Sample size Total N = 144,239	Setting: Patients who underwent TSA or RTSA	Dislocation (1 yr), n (%) 1. 1777 (1.7)
					Revision TSA (8 yr), n (%)

	Follow-up 1 yr for infection, dislocation, component loosening, and periprosthetic fracture Up to 8 yr for revision TSA 90-d medical complications for VTE Country of origin: USA No. of surgeons performing procedure: not reported Surgical technique: not reported	2. Obese (BMI of 30-39.9) 3. Morbidly obese (BMI of 40-49.9) 4. Super obese (BMI $\geq$ 50) Procedure: TSA and RTSA Indication for procedure: not reported	1. n = 105,661 2. n = 23,864 3. n = 13,759 4. n = 955 Demographic characteristics Age, % <65 yr 1. 6.4 2. 7.8 3. 15.4 4. 27.1 65-80 yr 1. 68.6 2. 76.9 3. 74.7 4. 68.4 >80 yr 1. 25.0 2. 15.2 3. 9.9 4. 4.5 Sex, n (%) 1. 62,763 F (59.4)/42,898 M (40.6) 2. 15,130 F (63.4)/8734 M (36.6) 3. 9893 F (71.9)/3866 M (28.1) 4. 801 F (83.9)/154 M (16.1) Ethnicity/nationality: not reported DM comorbidity, n (%) 1. 29,662.6 (28.1) 2. 11,454.7 (48.0) 3. 8379.2 (60.9) 4. 660.9 (69.2)	from 2005 to 2012 were identified by ICD-9 procedure codes: 81.80 and 81.88. Patient data were collected from the PearlDiver patient records database (PearlDiver Inc., Fort Wayne, IN, USA). Exclusions: No patients undergoing shoulder hemiarthroplasty were included.	2. 867 (3.6) 3. 666 (4.8) 4. 41 (4.3) OR (95% CI); *P* value 4 vs. 1: 1.8 (1.2-2.6); .004 4 vs. 2: 1.3 (0.9-1.9); .278 4 vs. 3: 1.0 (0.7-1.5); .941 PP fracture (1 yr), n (%) 1. 1454 (1.4) 2. 615 (2.6) 3. 368 (2.7) 4. 26 (2.7) OR (95% CI); *P* value 4 vs. 1: 1.4 (0.9-2.2); .222 4 vs. 2: 1.3 (0.8-2.1); .336 4 vs. 3: 0.9 (0.6-1.5); .909	1. 3202 (3.0) 2. 1021 (4.3) 3. 653 (4.7) 4. 42 (4.4) OR (95% CI); *P* value 4 vs. 1: 1.5 (1.1-2.0); .019 4 vs. 2: 1.1 (0.8-1.5); .538 4 vs. 3: 1.0 (0.7-1.4); .97 Medical complications (90 d), n (%) 1. 4295 (4.1) 2. 2967 (12.4) 3. 2630 (19.1) 4. 271 (28.4) OR (95% CI); *P* value 4 vs. 1: 2.7 (2.2-3.4); <.0001 4 vs. 2: 2.1 (1.7-2.6); <.0001 4 vs. 3: 1.6 (1.3-1.9); <.0001
Gupta et al[19]	Study design: retrospective cohort study Follow-up: minimum of 90 d Country of origin: USA No. of surgeons performing procedure: not reported Surgical technique: not reported	Exposure 1. Normal BMI (BMI < 25) 2. Class 1 obesity (BMI of 25-35) 3. Class 2 Obesity (BMI > 35) Procedure: RTSA Indication for procedure	Sample size Total N = 119 1. n = 30 2. n = 65 3. n = 24 Demographic characteristics Age, mean (SD), yr Total, 73.3 (9.8)	Setting: Patients who had undergone primary RTSA with a minimum 90-d postop follow-up were included (Department of Orthopedic Surgery, Rush University Medical Center, Chicago, IL, USA).	Dislocation, n (%) 1. 1 (3.3) 2. 2 (3.1) 3. 2 (8.3)	

(*continued on next page*)

Table II Summary of characteristics of included studies (*continued*)

Included study	Methods	Exposure and arthroplasty procedure	Participants/Patients	Setting and exclusions	Complications and postop outcomes
		RC tear arthropathy, n = 45 Massive and/or irreparable RC tear, n = 19 End-stage GH arthritis with irreparable RC tear, n = 35 Inflammatory arthropathy, n = 6 PH malunion with associated irreparable RC tear, n = 12	1. 75.7 (8.2) 2. 74.1 (9.8) 3. 68.4 (10.5) Sex, n (%) Total, 76 F (64)/43 M (36) 1. 22 F (73)/8 M (27) 2. 37 F (57)/28 M (43) 3. 18 F (75)/6 M (25) Ethnicity/nationality: not reported DM comorbidity: The authors reported DM comorbidity for all patients who had a complication of interest. Among the outcomes of interest in this review, 1 patient with a BMI > 40.0 experienced a dislocation.	Exclusions: patients with previous shoulder arthroplasty; RTSA performed as revision for failed prior arthroplasty (hemiarthroplasty or TSA); prior deep space infection requiring explantation; or incomplete records	
Chalmers et al[6]	Study design: retrospective cohort study Follow-up: minimum of 90 d Country of origin: USA No. of surgeons performing procedure: 1 Surgical technique: not reported	Exposure 1. Normal BMI (BMI <) 2. Obesity class I (BMI of 25-35) 3. Obesity class II (BMI > 35.0) Procedure: TSA Indication for procedure: OA, n = 120 Post-traumatic arthropathy, n = 4 Instability-related arthropathy, n = 3	Sample size Total N = 127 1. n = 15 2. n = 91 3. n = 21 Demographic characteristics Age, mean, yr 1. 66.3 2. 65.8 3. 65.2 Sex, n (%) 1. 10 F (67)/5 M (33) 2. 36 F (40)/55 M (60) 3. 13 F (62)/8 M (38) Ethnicity/nationality: not reported DM comorbidity: not reported	Setting: all patients who underwent TSA by senior author with minimum of 90 d of postop follow-up (Department of Orthopedic Surgery, Rush University Medical Center) Exclusions: history of ipsilateral shoulder arthroplasty or incomplete perioperative or postop records	Dislocation, n (%) 1. 0 (0.0) 2. 2 (2.2) 3. 0 (0.0)

Li et al[30]	Study design: prospective cohort study Follow-up: up to 2 yr Country of origin: USA No. of surgeons performing procedure: multiple Surgical technique: unconstrained anatomic TSA	Exposure 1. Normal (BMI $<$ 25) 2. Overweight (BMI of 25-29.9) 3. Obese (BMI $\geq$ 30) Procedure: TSA Indication for procedure: OA, RA, or post-traumatic arthritis	Sample size Total N = 76 1. n = 26 2. n = 25 3. n = 25 Demographic characteristics Age, mean (SD), yr 1. 71 (9) 2. 71 (11) 3. 68 (8) Sex, n Total, 49 F/27 M 1. 17 F/9 M 2. 15 F/10 M 3. 18 F/8 M Ethnicity/nationality: not reported DM comorbidity: not reported	Setting: Patients who underwent unconstrained anatomic TSA in a single hospital between January 1, 2009, and January 31, 2010, were enrolled in the prospective total shoulder registry, grouped according to BMI, and followed up prospectively for 2 yr Exclusions: patients who had undergone hemiarthroplasty, reverse shoulder arthroplasty, or any revision surgery as index procedure	Function, preop vs. postop (2 yr) ASES score, mean (SD) 1. 38.4 (15.5) vs. 80.2 (19.4) 2. 37.4 (18.1) vs. 75.2 (24.9) 3. 35.8 (12.5) vs. 80.0 (20.6) Quality of life, preop vs. postop (2 yr) SF-36 PCS, mean (SD) 1. 38.3 (6.5) vs. 53.1 (11.3) 2. 36.1 (8.0) vs. 39.8 (12.2) 3. 36.3 (8.4) vs. 40.7 (12.4) SF-36 MCS, mean (SD) 1. 47.4 (14.3) vs. 52.8 (10.0) 2. 49.7 (11.6) vs. 51.7 (11.5) 3. 51.5 (12.5) vs. 52.9 (11.6)	Pain, preop vs. postop (2 yr), points VAS–Pain score 1. 62 vs. 12 2. 68 vs. 18 3. 66 vs 11 Return to operating theater, n (%) Cause: deep infection 1. 0 (0.0) 2. 1 (4.0) 3. 0 (0.0) Revision TSA (2 yr), n (%) 1. 2 (7.7) 2. 0 (0.0) 3. 0 (0.0)
Mau et al[34,*]	Study design: retrospective cohort study Follow-up: average of 39.8 ± 18.7 mo (minimum of 2 yr) Country of origin: USA No. of surgeons performing procedure: 12 Surgical technique: prosthesis (Equinoxe; Exactech, Gainesville, FL, USA)	Exposure 1. BMI $<$ 25 2. BMI of 25-35 3. BMI $>$ 35 Procedure: TSA and RTSA Indication for procedure Degenerative arthritis, n = 499 RC arthropathy or OA, n = 612	Sample size TSA 1. n = 110 2. n = 290 3. n = 99 RTSA 1. n = 196 2. n = 357 3. n = 59 Demographic characteristics Age, mean (SD), yr TSA 1. 68.1 (9.8) 2. 66 (8.9) 3. 63.7 (7.2) RTSA 1. 73.5 (7.7) 2. 71.3 (7.7) 3. 68.9 (8.6) Sex, n TSA 1. 79 F/31 M 2. 134 F/156 M 3. 52 F/47 M	Setting: Patient data were gathered from a multi-institutional database. Patients were treated using either TSA or RTSA with 1 platform shoulder system. Exclusions: none reported	TSA group Function, preop vs. postop SST score, mean (SD) 1. 4.3 (2.6) vs. 10.5 (2.2) 2. 3.8 (2.7) vs. 10.4 (2.4) 3. 3.0 (2.8) vs. 10.0 (2.8) UCLA score, mean (SD) 1. 14.8 (3.7) vs. 31.3 (5.1) 2. 14.6 (3.9) vs. 30.1 (6.0) 3. 12.8 (4.3) vs. 30.2 (5.7) ASES score, mean (SD) 1. 40.0 (15.0) vs. 87.4 (17.7) 2. 38.5 (12.6) vs. 84.2 (19.9) 3. 31.1 (15.8) vs. 81.2 (21.4) Constant score, mean (SD) 1. 39.2 (14.1) vs. 73.1 (12.5) 2. 37.8 (12.6) vs. 71.2 (15.1) 3. 31.0 (11.6) vs. 67.9 (17.4)	RTSA group Function, preop vs. postop SST score, mean (SD) 1. 2.7 (2.3) vs. 10.0 (2.4) 2. 2.8 (2.8) vs. 9.9 (2.6) 3. 2.9 (2.9) vs. 10.3 (2.2) UCLA score, mean (SD) 1. 12.1 (3.9) vs. 30.1 (5.2) 2. 12.4 (4.2) vs. 30.3 (4.9) 3. 12.8 (5.1) vs. 30.5 (4.9) ASES score, mean (SD) 1. 35.0 (16.0) vs. 84.3 (17.3) 2. 32.3 (17.0) vs. 84.4 (17.3) 3. 33.0 (21.4) vs. 86.0 (15.3)

(*continued on next page*)

Table II Summary of characteristics of included studies (*continued*)

Included study	Methods	Exposure and arthroplasty procedure	Participants/Patients	Setting and exclusions	Complications and postop outcomes	
			RTSA 1. 138 F/58 M 2. 217 F/140 M 3. 34 F/25 M Ethnicity/nationality: not reported DM comorbidity: not reported		SPADI score, mean (SD) 1. 79.0 (19.1) vs. 13.8 (20.4) 2. 80.6 (21.8) vs. 18.4 (24.9) 3. 90.0 (21.3) vs. 22.1 (26.1) Act abduction, mean (SD)† 1. 83.5 (28.0) vs. 122.9 (29.8) 2. 80.2 (27.1) vs. 120.1 (30.2) 3. 77.4 (25.7) vs. 116.2 (31.9) Act forward flexion, mean (SD)† 1. 100.3 (33.5) vs. 144.4 (30.8) 2. 95.8 (30.6) vs. 139.9 (32.0) 3. 88.7 (27.3) vs. 141.2 (34.2) IR, mean (SD)† 1. 3.3 (1.6) vs. 5.7 (1.2) 2. 2.8 (1.5) vs. 5.2 (1.4) 3. 2.7 (1.4) vs. 4.4 (1.6) Act ER, mean (SD)† 1. 17.2 (19.9) vs. 50.2 (20.6) 2. 16.2 (19.9) vs. 45.7 (20.4) 3. 14.2 (17.1) vs. 42.6 (19.7)	Constant score, mean (SD) 1. 30.2 (14.0) vs. 71.1 (14.4) 2. 30.1 (14.8) vs. 71.5 (15.2) 3. 30.8 (18.2) vs. 72.2 (15.1) SPADI score, mean (SD) 1. 85.2 (22.1) vs. 20.2 (23.8) 2. 83.1 (21.8) vs. 21.5 (24.8) 3. 79.2 (25.1) vs. 19.9 (20.4) Act abduction, mean (SD)† 1. 60.0 (33.5) vs. 102.7 (24.9) 2. 65.0 (35.5) vs. 106.1 (26.0) 3. 69.2 (34.1) vs. 105.7 (25.7) Act forward flexion, mean (SD)† 1. 80.5 (40.7) vs. 140.4 (26.0) 2. 82.7 (41.0) vs. 139.6 (28.4) 3. 85.7 (41.2) vs. 132.6 (32.6) IR, mean (SD)† 1. 3.1 (1.8) vs. 4.9 (1.4) 2. 2.9 (1.8) vs. 4.5 (1.7) 3. 2.4 (1.7) vs. 4.0 (1.7) Act ER, mean (SD)† 1. 10.7 (21.8) vs. 32.3 (13.1) 2. 13.2 (21.2) vs. 32.8 (16.2) 3. 14.5 (21.0) vs. 31.1 (14.2)

Beck et al[4]	Study design: retrospective cohort study Follow-up: minimum of 2 yr Country of origin: USA No. of surgeons performing procedure: 1 Surgical technique: deltoid-splitting approach; deltopectoral approach	Exposure 1. Normal (BMI of 18.5-24.9) 2. Overweight: (BMI of 25-29.9) 3. Obese (BMI $\geq$ 30) Procedure: RTSA Indication for procedure: RC arthropathy	Sample size Total N = 76 1. n = 23 2. n = 36 3. n = 17 Demographic characteristics Age, mean (range), yr Total, 75 (51-88) Sex, n 1. 13 F/10 M 2. 19 F/17 M 3. 12 F/5 M Ethnicity/nationality: not reported DM comorbidity, n (%) 1. 1 (4.3) 2. 7 (19.4) 3. 8 (47.1)	Setting: Patients undergoing RTSA for RC arthropathy by a single surgeon from January 1, 2005, to March 1, 2010, were included. The inclusion criteria included patient age > 18 yr, primary diagnosis of RC arthropathy, minimum 2-yr follow-up, and subsequent RTSA by senior author. Exclusions: patients with history of infection	Function, postop Act forward flexion, mean (SD)[†] 1. 134 (32) 2. 129 (43) 3. 117 (44) Act abduction, mean (SD)[†] 1. 99 (26) 2. 100 (41) 3. 86 (27) Act ER, mean (SD)[†] 1. 26 (15) 2. 33 (17) 3. 23 (18)	Pain, mean (SD), points VAS–Pain score, postop 1. 1.5 (1) 2. 2.6 (3) 3. 3.0 (3)
Pappou et al[35]	Study design: case-control study Follow-up: minimum of 2 yr Country of origin: USA No. of surgeons performing procedure: 1 Surgical technique: prosthesis (reverse shoulder prosthesis; DJO Surgical, Austin, TX, USA); all patients received deltopectoral approach.	Exposure 1. Obese (BMI $\geq$ 40) 2. Controls (BMI < 30) Procedure: RTSA Indication for procedure RC tear arthropathy, n = 68 Massive RC tear, n = 8 RA, n = 8	Sample size Total N = 84 1. n = 21 2. n = 63 Demographic characteristics Age, mean (range), yr 1. 69.2 (7.1) 2. 71.1 (6.4) Sex, n 1. 17 F/4 M 2. 50 F/13 M Ethnicity/nationality: not reported DM comorbidity: not reported	Setting: A prospective database was retrospectively searched for morbidly obese patients with a BMI $\geq$ 40 who had undergone primary RTSA for a reason other than fracture from January 1, 2003, to December 31, 2010. Three controls for each morbidly obese patient were matched on the basis of age, sex, surgical indication, and duration of follow-up. Exclusions: patients receiving RTSA for treatment of PH fracture, patients who had incomplete clinical and radiographic data, or <2-yr follow-up	Function, preop vs. postop, mean (SD) VAS–Function score 1. 2.1 (2.1) vs. 6.9 (2.4) 2. 3.6 (2.4) vs. 7.8 (2.2) ASES score, mean (SD) 1. 32.0 (12.8) vs. 69.0 (16.0) 2. 39.9 (17.8) vs. 78.2 (18.6) SST score, mean (SD) 1. 1.1 (1.1) vs. 7.0 (3.4) 2. 2.1 (1.9) vs. 8.2 (2.9) Forward flexion, mean (SD)[†] 1. 61 (26) vs. 139 (39) 2. 74 (42) vs. 153 (31) Abduction, mean (SD)[†] 1. 56 (20) vs. 125 (49) 2. 68 (35) vs. 138 (40) ER, mean (SD)[†] 1. 11 (25) vs. 54 (35) 2. 26 (26) vs. 55 (33) IR (vertebral levels) 1. L5 (2) vs. T12 (2) 2. L3 (2) vs. T12 (2)	Pain, preop vs. postop, mean (SD) VAS–Pain score 1. 6.6 (1.9) vs. 2.2 (2.9) 2. 6.2 (2.2) vs. 1.3 (2.2) Acromial fracture, n (%) 1. 2 (9.5) 2. 1 (1.6) Revision, n (%) Cause: humeral stem loosening 1. 0 (0.0) 2. 1 (1.6) (revision occurred at 75 mo after RTSA)

(*continued on next page*)

Table II Summary of characteristics of included studies (*continued*)

Included study	Methods	Exposure and arthroplasty procedure	Participants/Patients	Setting and exclusions	Complications and postop outcomes
Singh et al[39]	Study design: retrospective cohort study Follow-up: mean, 7 yr; range, 1 d to 31 yr Country of origin: USA No. of surgeons performing procedure: not reported Surgical technique Cemented implants in 2485 No cement in 103	Exposure 1. BMI $\leq$ 24 2. BMI of 25-29.9 3. BMI of 30-35.9 4. BMI of 35-39.9 5. BMI $\geq$ 40 Procedure: TSA Indication for procedure RA, n = 452 Trauma related, n = 374 OA, n = 1640 Other, n = 122	Sample size Total N = 2588 1. n = 475 2. n = 744 3. n = 521 4. n = 235 5. n = 126 Demographic characteristics Age: mean (median), yr Total, 65 (67) Sex, n 1372 F/1216 M Ethnicity/nationality: not reported DM comorbidity: not reported	Setting: Every patient in whom primary shoulder arthroplasty was performed when they were aged $\geq$ 18 yr, at Mayo Clinic Medical Center, Rochester, MN, USA, in the 33-yr period from 1976 to 2008, was included. Periprosthetic shoulder fractures were identified from the total joint registry. Exclusions: not reported	PP fracture, n (%) 1. 7 (1.5) 2. 1 (0.1) 3. 2 (0.4) 4. 3 (1.3) 5. 2 (1.6)
Singh et al[40]	Study design: retrospective cohort study Follow-up: up to 20 yr Country of origin: USA No. of surgeons performing procedure: not reported Surgical technique: not reported	Exposure: total BMI; mean, 30 (SD, 6) Procedure: TSA Indication for procedure RA, n = 452 Trauma, n = 374 Tumor, n = 37 OA, n = 1640 RC disease, n = 40 Other, n = 30	Sample size: total N = 2588 Demographic characteristics Age, mean (SD), yr Total, 65 (12) Sex, n (%) Total, 1163 F (53)/1044 M (47) Ethnicity/nationality: not reported DM comorbidity: not reported	Setting: All patients who had undergone TSA between January 1976 and December 2008 at Mayo Clinic Medical Center, Rochester, MN, USA, were included. BMI data were only available from 1987 onward. Exclusions: not reported	Revision—univariate regression analysis: HR, 1.01 (95% CI, 0.99-1.04); *P* = .29

postop, postoperative; *BMI*, body mass index (kg/m^2); *TSA*, total shoulder arthroplasty; *RTSA*, reverse total shoulder arthroplasty; *n*, number of arthroplasties; *SD*, standard deviation; *F*, female; *M*, male; *DM*, diabetes mellitus; *RR*, relative risk; *CI*, confidence interval; *VTE*, venous thromboembolism; *ICD-9*, *International Classification of Diseases, Ninth Revision*; *OR*, odds ratio; *RC*, rotator cuff; *GH*, glenohumeral; *PH*, proximal humeral; *OA*, osteoarthritis; *RA*, rheumatoid arthritis; *preop*, preoperative; *ASES*, American Shoulder and Elbow Surgeons; *SF-36*, Short Form 36; *VAS*, visual analog scale; *SST*, Simple Shoulder Test; *UCLA*, University of California at Los Angeles; *SPADI*, Shoulder Pain and Disability Index; *Act*, active; *IR*, internal rotation (in degrees); *ER*, external rotation (in degrees); *HR*, hazard ratio; *PP*, periprosthetic; *SF-36 PCS* and *SF-36 MCS*, short form-36, physical component summary and mental component summary.

* Mau et al[34] reported TSA and RTSA data separately. As the RTSA subset constituted a greater proportion of the overall study sample, the data from the RTSA subset were included in the meta-analyses.

† All range-of-motion measurements (forward flexion, abduction, ER, and IR) are presented in degrees unless otherwise stated.

and included either a minimum of 90 days or up to 1 year (Table II). Meta-analyses revealed increased odds of a dislocation in patients with a BMI of 30.0 kg/m^2 or greater (OR, 2.49; 95% CI, 2.32-2.66) compared with patients with a BMI of less than 30.0 kg/m^2 (Fig. 2).

Analysis revealed TSA and RTSA patients who were obese had a 1.92 times greater odds of periprosthetic fracture than non-obese patients (Table III). Furthermore, 1 study reported the incidence of acromial fracture between morbidly obese and non-obese RTSA patients, who were followed up for a minimum of 2 years.[35] This study was combined with studies that reported on periprosthetic fracture to provide an overall analysis on the odds of fracture. The results revealed that patients who were morbidly obese had a 1.98 times greater odds of fracture than non-obese patients (OR, 1.98; 95% CI, 1.77-2.21). As the analysis was heavily weighted on the findings of Werner et al,[50] a sensitivity analysis was conducted, the results of which are presented in Table III. No statistically significant heterogeneity was observed in these meta-analyses (Table III).

Three studies reporting on a total of 144,399 TSA and RTSA patients were able to contribute to a meta-analysis investigating revision. The postoperative follow-up duration varied across studies and included up to 2 years,[30] a minimum of 2 years,[35] and up to 8 years.[50] Analysis revealed that TSA and RTSA patients who were obese had a 1.49 times greater odds of undergoing revision than non-obese patients at up to 8 years after surgery (Fig. 3, *A*). The odds of revision increased to 1.59 times in patients with a BMI of 40.0 kg/m^2 or greater (Fig. 3, *B*). No statistically significant heterogeneity was observed in these meta-analyses; however, the analyses were heavily weighted with the findings of a single study.[50] The results of the sensitivity analysis are presented in Table III.

Two studies reported an unscheduled return to the operating theater[27,30] (Table II). This analysis does not include studies that explicitly stated a return to the operating theater because of "revision surgery." Analysis revealed that the odds of an unscheduled return to the operating theater following TSA or RTSA were no different between patients who were obese and those with a BMI of less than 30 kg/m^2 (Table III). No statistical heterogeneity ($I^2 = 0\%$) was observed; however, this is expected given the large variance in the study by Li et al.[30]

Effect of obesity on function, pain, and QoL

No statistically significant difference in American Shoulder and Elbow Surgeons (ASES) questionnaire scores was found between TSA and RTSA patients who were obese and those who were non-obese (Table III). Postoperative mean ASES scores ranged from 69 to 80 in patients who were obese compared with 78 to 84 in patients who were not obese, with higher scores indicating better self-reports of pain, instability, and activities of daily living. Heterogeneity was not statistically significant ($P = .08$); however, the I^2 statistic identified substantial statistical heterogeneity between studies, limiting plausible conclusions ($I^2 = 61\%$).

Three studies reported range-of-motion (ROM) measurements for a follow-up period of, at minimum, 2 years.[4,34,35] Two studies indicated that ROM measurements were active movements[4,34]; however, the remaining study did not specify this.[35] Following RTSA, no statistically significant WMD was observed in abduction (WMD, –0.78°; 95% CI, –7.27° to 5.71°) or external rotation (WMD, –1.41°; 95% CI, –5.11° to 2.29°) ROM measures between patients who were obese and those who were not obese. Conversely, meta-analysis revealed a statistically significant difference in postoperative forward flexion ROM in patients with obesity. The WMD was –9.80° (95% CI, –17.53° to –2.07°), indicating that after RTSA, patients with a BMI of 30.0 kg/m^2 or greater showed less forward flexion ROM than patients with a BMI of less than 30.0 kg/m^2. Recent research has reported that the minimal clinically importance difference (MCID) for active forward flexion in TSA and RTSA patients is 12° ± 4°, suggesting that the difference observed in this review may be clinically relevant.[38] No statistically significant heterogeneity was observed (Table III).

RTSA patients who were obese had a statistically significant increase in pain compared with non-obese RTSA patients, as measured by the visual analog scale for pain (VAS-P). The WMD was 1.13 (95% CI, 0.21-2.06), indicating patients with a BMI of 30.0 kg/m^2 or greater experienced slightly greater postoperative pain scores than patients with a BMI of less than 30.0 kg/m^2 (Table III). No statistical heterogeneity was observed. Figure 4 shows that the mean range of VAS-P scores was 1.3 to 3, indicating that both groups had no pain[26] or had mild pain. Recent research has suggested that the MCID for the VAS-P score in shoulder arthroplasty patients is 1.4, indicating that although a WMD on the VAS-P was observed in patients who were obese compared with non-obese patients, it was not clinically relevant.[41]

Only 1 TSA study investigated the impact of this comorbidity on QoL.[30] The authors concluded that TSA patients who were obese or overweight failed to reach the level of physical function improvement achieved by patients with a BMI in the normal range.

Discussion

With the number of upper-limb arthroplasty procedures predicted to rise, risk factors that predispose patients to poorer outcomes must be thoroughly investigated. Following resolution of any early complications, joint prostheses are ideally expected to function for 15 to 20 years before a revision is required. Unfortunately, our review findings suggest that TSA and RTSA patients who are

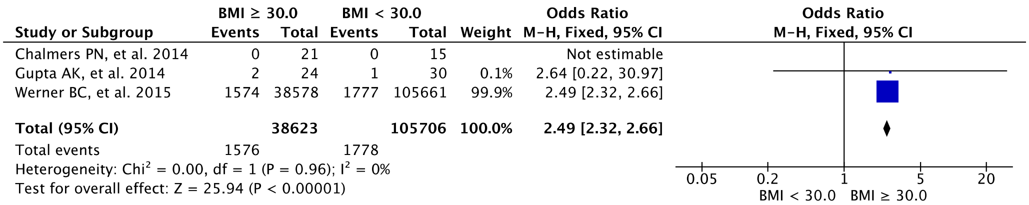

Figure 2 Forest plot of odds of dislocation in various body mass index *(BMI)* groups: obese (BMI ≥ 30.0 kg/m^2) vs. non-obese (BMI < 30.0 kg/m^2) total shoulder arthroplasty and reverse total shoulder arthroplasty patients. The follow-up periods were a minimum of 90 days and up to 1 year. *M-H*, Mantel-Haenszel; *CI*, confidence interval; *df*, degrees of freedom.

obese are at greater risk of revision. Revision was reported in studies with follow-up durations of up to 2 years,[30] up to 8 years,[50] and a minimum of 2 years.[35] The study with a minimum 2-year follow-up reported that the revision was performed 6.3 years after primary arthroplasty.[35] A revision required within these study follow-up periods (<10 years) is indicative of early-term to midterm failure of the prosthesis, which is a detrimental outcome.

Common causes of prosthesis revision following TSA and RTSA are instability and dislocation.[3] This review found that patients who were obese were at greater risk of dislocation following TSA or RTSA. One study reported a dislocation within 1 year,[50] whereas the second study simply stated there was a minimum 90-day follow-up period without specifying how long after the arthroplasty procedure the dislocation occurred.[19] Regarding RTSA, instability of the joint can be caused by inadequate tensioning of the deltoid muscle and conjoint tendon.[7] Chalmers et al[7] suggested that obesity contributes to instability by hindering accurate intraoperative soft-tissue tensioning. A heightened risk of dislocation with increasing BMI has also been reported in the lower-limb arthroplasty population. For example, obese total hip arthroplasty patients have been shown to have a 2.08 times greater risk of dislocation.[31] More recently, Wagner et al[48] reported a linear relationship between risk of early dislocation and BMI in a total hip arthroplasty population.

Other less common causes of revision surgery include periprosthetic and acromial fractures. This review found that TSA and RTSA patients who were obese had an approximately 2 times greater odds of fracture than patients who were not obese. Unfortunately, most of the studies reporting the incidence of fracture did not specify whether the fractures occurred intraoperatively or postoperatively. If there is a greater risk of intraoperative fracture in patients with a high BMI, it may suggest greater technical difficulties with the procedure in patients who are obese; however, this could not be determined or explored further.

Shoulder pain for 3 months or longer has been linked to depression,[8] anxiety, and sleep disturbance, which have been shown to improve following arthroplasty.[9] The review findings showed that RTSA patients who were obese reported slightly greater postoperative pain scores than non-obese patients, at a WMD of 1.13 on the VAS-P. As the MCID of the VAS-P score is greater than this (1.4 in the shoulder arthroplasty population),[41] this finding has minimal clinical relevance. Furthermore, the mean range of VAS-P scores was 1.3 to 3, indicating that both the obese and non-obese groups experienced no pain or only mild pain postoperatively. Similarly, our review findings correspond with research on pain relief and obesity in the lower limb. Most recently, Li et al[29] found that patients across all BMI groups, from normal through morbidly obese, showed substantial improvements in pain at 6 months.

Three new studies eligible for this review were published after the search was conducted (May 27, 2016).[1,45,47] Wagner et al[47] presented comparable results, showing that for every 1-unit increase in BMI of 30 kg/m^2 or greater, there was a 5% increased risk of revision due to mechanical failure. However, no significant associations were found between BMI groups and outcomes including reoperation and revision (all reasons).[47] The study by Wagner et al also examined the risk of periprosthetic fracture and dislocation and, contrary to the present results, found no association with obese and non-obese categories.

The present review findings corroborate most of the results of a retrospective cohort study that investigated the midterm functional outcomes and QoL of obese patients following TSA and RTSA.[45] The study reported improvements in postoperative ASES scores and active external rotation across all BMI categories. However, lower levels of improvement in active external rotation were noted. Vincent et al[45] also reported no significant effects of obesity on additional patient-reported outcome measures of function, pain, and general health including Shoulder Pain and Disability Index, University of California at Los Angeles shoulder rating scale, Constant, and Short Form 12 scores. However, lower Short Form 12 scores were found in patients who were morbidly obese. The final study we identified presented conflicting results, suggesting no association between high BMI and risk of aseptic revision.[1]

When considering the findings presented, several limitations are worth noting. First, patient and surgical factors can also impact a number of outcomes investigated in this review. Younger age (<65 years) has been significantly associated with early revision.[49] Similarly, increasing age, female sex, and rheumatoid arthritis have been identified as risk factors for periprosthetic fracture of the humerus.[13] Furthermore, surgical technique and implant type were not uniform across included studies, which may have

Table III Meta-analysis summary

Outcome	No. of studies	Total patients, n	Events, n	Heterogeneity (I^2), %	Statistical method	Effect estimate	*P* value
Dislocation for obese vs. non-obese (all*)	3	144,329	3354	0	OR (M-H, fixed, 95% CI)	2.49 (2.32-2.66)	<.00001
Periprosthetic fracture for obese vs. non-obese	2	146,340	2478	0	OR (M-H, fixed, 95% CI)	1.92 (1.77-2.08)	<.00001
Fracture for morbidly obese vs. non-obese	3	121,804	1861	0	OR (M-H, fixed, 95% CI)	1.98 (1.77-2.21)	<.0001
Fracture for morbidly obese vs. non-obese† with removal of heavily weighted study	2	1429	13	0	OR (M-H, fixed, 95% CI)	3.40 (0.97-11.97)	.06
Pain score (VAS–Pain) for obese vs. non-obese	2	124	—	0	WMD (I-V, fixed, 95% CI)	1.13 (0.21-2.06)	.02
ASES functional score for obese vs. non-obese	3	390	—	61	WMD (I-V, fixed, 95% CI)	−0.80 (−4.57 to 2.97)	.68
Abduction functional score for obese vs. non-obese (all*)	3	379	—	53	WMD (I-V, fixed, 95% CI)	−0.78 (−7.27 to 5.71)	.81
External rotation functional score for obese vs. non-obese (all*)	3	379	—	0	WMD (I-V, fixed, 95% CI)	−1.41 (−5.11, 2.29)	.45
Forward flexion functional score for obese vs. non-obese (all*)	3	379	—	0	WMD (I-V, fixed, 95% CI)	−9.80 (−17.53 to −2.07)	.01
Unscheduled return to operating theater for obese vs. non-obese	2	4343	35	0	OR (M-H, fixed, 95% CI)	0.83 (0.43-1.61)	.58
Revision (all*) for obese vs. non-obese	3	144,399	4921	0	OR (M-H, fixed, 95% CI)	1.49 (1.40-1.58)	<.0001
Revision (all*) for obese vs. non-obese† with removal of heavily weighted study	2	160	3	0	OR (M-H, fixed, 95% CI)	0.57 (0.06-5.19)	<.0001
Revision for morbidly obese vs. non-obese	2	120,459	3898	0	OR (M-H, fixed, 95% CI)	1.59 (1.46-1.72)	<.0001

OR, odds ratio; *M-H*, Mantel-Haenszel; *CI*, confidence interval; *VAS–Pain*, visual analog scale for pain; *WMD*, weighted mean difference; *I-V*, inverse variance; *ASES*, American Shoulder and Elbow Surgeons.

The body mass index groups were as follows: normal, less than 25.0 kg/m^2; overweight, 25.0 to 29.9 kg/m^2; obese, 30.0 to 39.9 kg/m^2 (or obese class 2 [35.0-39.9 kg/m^2]); morbidly obese, 40.0 kg/m^2 or greater; and non-obese, less than 30.0 kg/m^2.

* All studies that reported this outcome were combined in the meta-analysis comparing body mass index lower than 30.0 kg/m^2 vs. 30.0 kg/m^2 or greater, despite variations in individual study body mass index groupings.

† A sensitivity analysis was performed with removal of the heavily weighted study for the following: fracture for morbidly obese vs. non-obese patients and revision (all) for obese vs. non-obese patients.

influenced outcomes such as dislocation. Second, the level of evidence of included studies was low; however, this is an inherent consequence of research investigating risk due to exposure. Given the retrospective nature of most included studies, and that all studies gathered data from an American patient population, we are unable to confirm no patient overlap across studies. A further issue is the use of BMI as a measurement tool to define obesity, given that this measure has several well-acknowledged shortcomings.[5] Similarly, the studies rarely specified the equipment used to measure BMI. Researchers should endeavor to report additional information including what equipment was used to measure height and weight, who performed these measurements, and what patients wore while being measured.

The review process also imposed several limitations. First, the comprehensive search strategy, with no

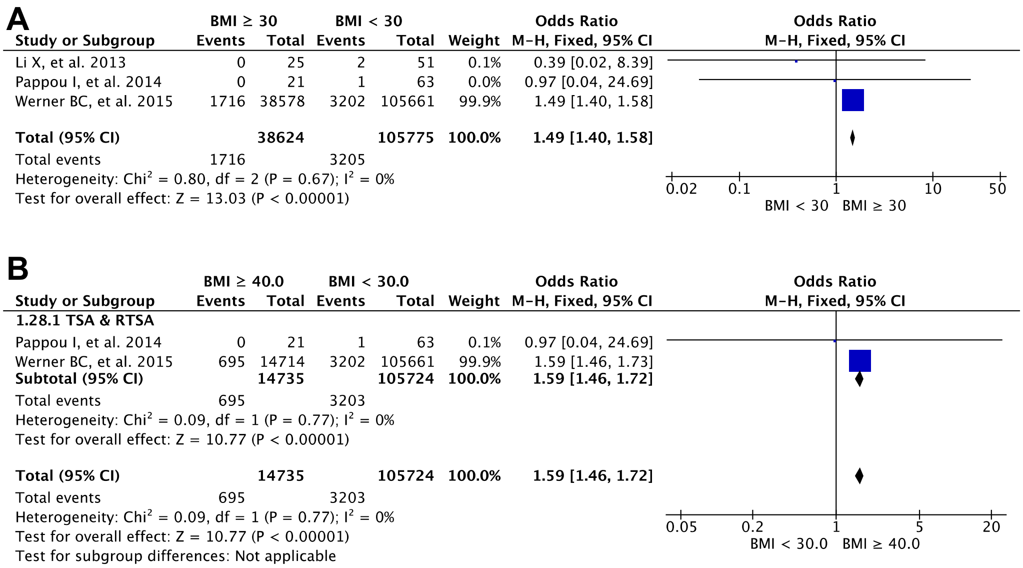

Figure 3 Forest plots of odds of revision in various body mass index *(BMI)* groups: (**A**) obese (BMI $\geq$ 30.0 kg/m^2) vs. non-obese (BMI $<$ 30.0 kg/m^2) and (**B**) morbidly obese (BMI $\geq$ 40.0 kg/m^2) vs. non-obese (BMI $<$ 30.0 kg/m^2) total shoulder arthroplasty *(TSA)* and reverse total shoulder arthroplasty *(RTSA)* patients. The follow-up periods were up to 2 years, a minimum of 2 years, and up to 8 years. *M-H*, Mantel-Haenszel; *CI*, confidence interval; *df*, degrees of freedom.

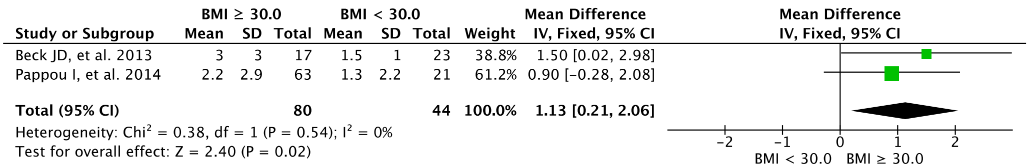

Figure 4 Weighted mean difference in postoperative pain scores between obese (body mass index *[BMI]* $\geq$ 30.0 kg/m^2) and non-obese (BMI $<$ 30.0 kg/m^2) reverse total shoulder arthroplasty patients. Postoperative pain was measured using a visual analog scale for pain (scale from 0 to 10, on which 0 indicates no pain). The follow-up period was a minimum of 2 years. *SD*, standard deviation; *IV*, inverse variance; *CI*, confidence interval; *df*, degrees of freedom.

publication date limits, was designed to locate all the available evidence; however, despite this, the restriction to include only English-language studies leaves the review at risk of language bias. The selection of studies for inclusion in this review was performed by only 1 reviewer, which can potentially cause errors of omission. Similarly, despite cross-checking all extracted data with study articles prior to analysis, data extraction was only conducted by a single reviewer, increasing the risk of errors in data handling. Finally, although the use of unadjusted data provided several advantages for data analysis, it leaves findings susceptible to other confounders such as comorbidity that could not be accounted for.

Conclusion

The results of the systematic review revealed that the odds of revision surgery increased with increasing BMI in shoulder arthroplasty patients. Similarly, obesity was found to increase the odds of dislocation and fracture but had no influence on the odds of an unscheduled return to the operating theater. No association was found between obesity and abduction or external rotation ROM; however, a statistically significant difference in postoperative forward flexion was observed. Patients who were obese reported significantly higher levels of pain; however, the difference was not clinically relevant, and limited evidence was available regarding the impact of obesity on QoL. Notably, the findings were limited by confounding variables such as the influence of patient and surgical factors. In addition, authors rarely described the method or equipment used to measure BMI, which should be reported to improve the comparability across studies in the future. Nevertheless, surgeons should consider advising patients who are obese of the greater risk of dislocation, fracture, and revision to promote well-informed decisions and to allow for precautionary measures to be undertaken prior to proceeding with surgery.

Acknowledgments

The authors thank Kenneth Lo (PhD candidate, The Joanna Briggs Institute) for contributions to the critical appraisal of included studies, Dr. Lucylynn Lizarondo (research fellow, The Joanna Briggs Institute) for guidance provided on systematic review methodology, and Maureen Bell (research librarian, The University of Adelaide) for assistance with development of the search strategy.

Disclaimer

Annika Theodoulou was supported by an Australian Government Research Training Program Scholarship. At the time of publication, Annika Theodoulou was funded by the National Institute for Health Research (NIHR) Oxford Biomedical Research Centre. The views expressed are those of the authors and not necessarily those of the National Health Service (NHS), the NIHR, or the Department of Health and Social Care. Both the other 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.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2019.06.017.

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