

- 1 Risk of complications in patients who are
 - 2 obese following upper limb arthroplasty: A
 - 3 systematic review and meta-analysis
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Abstract

Purpose

A systematic review was performed to investigate the impact of obesity on complications following total shoulder (TSA), reverse total shoulder (RTSA) and total elbow arthroplasty (TEA).

Methods

Electronic databases and grey literature were searched for studies that evaluated the influence of obesity (Body Mass Index [BMI] $\geq 30 \text{ kg/m}^2$) on upper-limb arthroplasty outcomes. Fifteen studies were identified, however only twelve reported predetermined outcomes. Unadjusted data was pooled in statistical meta-analysis where appropriate. Effect sizes were expressed as odds ratios (OR) for categorical data and weighted mean differences for continuous data.

Results

Odds of infection increased with increasing BMI, from 2.37 (95%CI[1.65,3.41]) times in patients who were obese, to greater than five times (OR=5.04; 95%CI[4.70,5.39]) in patients who were morbidly obese. Furthermore, patients who were obese or morbidly obese had 3.92 (95%CI[3.59,4.28]) to 5.46 (95%CI[4.91,6.07]) times greater odds of venous thromboembolism (VTE) compared to their non-obese counterparts, respectively. Conversely, obesity had no influence on the odds of urinary tract infection (OR=0.88;95%CI[0.48,1.61], or mortality (OR=1.79; 95%CI[0.79,4.03]). TSA/RTSA patients who were obese experienced operations 10.00 minutes longer (95%CI[6.31,13.69]) than patients with a BMI in the normal range, which increased to 12.48 minutes (95%CI[8.40,16.55]) in patients with a BMI ≥ 35.0 .

25 Evidence examining the influence of obesity on blood transfusion was inconclusive, while
26 minimal evidence was available on pneumonia.

27 **Conclusion**

28 Surgeons should consider advising patients who are obese of the greater risk of VTE and
29 infection when considering elective upper-limb arthroplasty. However, noteworthy limitations
30 surrounded the lack of information regarding prophylaxis regimes and BMI measurement tools
31 used in included studies.

32 **Keywords**

33 *Obesity; BMI; Complications; upper limb arthroplasty; total shoulder arthroplasty; total*
34 *elbow arthroplasty*

1. Introduction

Upper limb arthroplasty is an effective treatment commonly used in the medical care of the elderly population. In Australia, reverse total shoulder arthroplasty (RTSA) is the most widely performed total shoulder replacement procedure (53.2%), closely followed by anatomic total shoulder arthroplasty (TSA) (44.0%) (1). In comparison, total elbow arthroplasty (TEA) is relatively infrequent (1). With advancing age comes a greater risk of further chronic conditions, such as obesity, increasing the possibility of comorbid patients presenting for elective joint replacement.

Obesity is common in an older population (2), yet the available evidence on the impact of obesity on upper limb arthroplasty outcomes is inconclusive and contradictory (3). Complications and poor outcomes following arthroplasty can lead to increased morbidity in patients and prolonged length of stay (LoS). Additionally, in-hospital complications result in increased costs (4), imposing further burden on the healthcare system. Common arthroplasty complications include infection and blood loss requiring blood transfusion. Similarly, urinary tract infection (UTI) and pneumonia have been identified as significant predictors of hospital readmission following TSA (5). Complications such as venous thromboembolisms (VTE) and mortality are rare following upper limb arthroplasty. Reported incidences of VTE range from 0.2% to 13.0% in shoulder arthroplasty patients (5-8) and 0.8% in TEA patients (9). Nevertheless, VTE, and in particular death following an elective surgical procedure is a devastating outcome. With the increasing rate of upper limb arthroplasty procedures (1), further considerations must be given to prognostic factors that influence risk of such complications.

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

To date, research has considered a number of perioperative, short and longer-term complications for patients with comorbid conditions in isolation. A literature search identified two reviews investigating the effect of obesity on upper-limb arthroplasty, however authors did not address the question through systematic review nor meta-analysis (10, 11).

To investigate 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 infection, VTE, blood transfusion, UTI, pneumonia or mortality following TSA, RTSA and TEA? (2) Are obese patients at an increased risk of longer operative duration or LoS following TSA, RTSA and TEA?*

2. Materials and Methods

The present review was conducted in accordance with an *a priori* protocol of a larger review project investigating additional outcomes, and the influence of diabetes mellitus on upper limb arthroplasty outcomes (3, 12). This review was prospectively registered on PROSPERO (CRD42016053299).

2.1 Search Strategy and Criteria

A comprehensive three-step search strategy was undertaken across the PubMed, CINAHL and Embase databases on 27 May, 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 Open Grey. Detailed search strategies are available in the Appendix. The reference lists of all eligible studies were screened for additional studies.

2.2 Inclusion and Exclusion Criteria

Adults, 18 years or older, who had undergone primary TSA, RTSA or TEA were considered for inclusion. When the impact of obesity was considered for a combination of arthroplasty procedures including those on the lower limb (i.e. hip, knee, shoulder, elbow and/or hemiarthroplasty (HA)), study authors were contacted for specific data on the cohort of interest. If the data was not available, or a response was not received, the paper was deemed eligible for inclusion if it included $\geq 70\%$ of the population of interest (TSA, RTSA, TEA).

Eligible studies must have investigated the impact of obesity ($\text{BMI} \geq 30.0 \text{ kg/m}^2$) on outcome in isolation. The term *non-obese* has been used to describe patients categorised with a $\text{BMI} <$

30.0 kg/m². The obese category was further subdivided into *obese class 1* (BMI 30.0 – 34.9 kg/m²) and *obese class 2* (BMI ≥ 35.0), depending of the BMI groups reported in the primary studies. *Morbidly obese* indicated a BMI of ≥ 40.0 kg/m² and *normal range* refers to patients with a BMI < 25.0 kg/m².

The review considered cohort and case-control studies for inclusion. Studies reporting on one or more of the following outcomes are discussed in the present review: operative duration, LoS, infection (surgical-site and periprosthetic), VTE (Deep Vein Thrombosis [DVT] or Pulmonary Embolism [PE]), blood transfusion, UTI, pneumonia, mortality.

Database searching returned 9596 citations, which were transferred to Endnote X7 (Thomas Reuters, New York, 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 (AT). This initial title and abstract screening resulted in the exclusion of 6943 ineligible records. The full text of 260 studies were then retrieved for further assessment of eligibility, of which 229 studies were excluded (Fig. 1). Where necessary, inclusion was confirmed with discussion (EA). An additional 17 citations were identified via reference list screening of eligible studies. Eight records were excluded due to insufficient information to determine eligibility, following unsuccessful document retrieval requests, and requests for further information made to study authors (13-20). Twenty-three eligible studies were identified, however two could not be included in synthesis due to an overlapping patient population selected from the same national database (21, 22). An eligible study which reported on the same patient cohort was preferentially selected when the study provided the greatest representation, most recent or readily extractable data. Following breakdown by exposure, eight studies investigated diabetes mellitus alone and are discussed in a separate paper. Finally,

a total of 15 obesity studies were identified, with 12 studies reporting on outcomes relevant to the present review questions (23-34).

2.3 Assessment of Study Quality

A summary of the characteristics of included studies is presented in Table 1. Study designs included 10 retrospective cohort studies, (23-29, 31, 33, 34) one prospective cohort study (30) and one case-control study (32). Ten studies considered TSA and/or RTSA patient populations, while two studies evaluated TEA patients. All studies were conducted in the United States. Most studies retrospectively gathered data from national or multi-institutional healthcare and/or surgical databases (Table 1).

Methodological validity of included studies was assessed by two independent reviewers (AT, KL) using standardised critical appraisal tools (Joanna Briggs Institute [JBI] SUMARI) (35, 36). Appraisal was piloted with a subset of studies to determine suitability and consistency in understanding of the application of the tools between each reviewer. Any disagreements that arose were resolved through discussion and, where necessary for one study (31), through consultation with a third reviewer (EA). Assessments of appraisal questions relating to outcomes (refer cohort study design Q6, 7 and 8; Case-control study design Q8; Table 2) were re-evaluated by a single reviewer (AT). 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 (3). All eligible studies were included in the review irrespective of their methodological quality, with results summarised in Table 2.

The majority of cohort studies (90.9%) recruited participant groups from the same population (23-27, 29-31, 33, 34) and all measured outcomes and/or exposures similarly to assign study

groups (Table 2). However, few studies (18.2%) measured the outcome or exposure used to group participants in a valid and reliable way (31, 33). Most studies (90.9%) identified key confounders, specifically age, gender or comorbidities, however not all (72.7%) reported strategies to deal with such factors. In 81.8% of studies, it was deemed *Unclear* whether patients were free of the outcomes, specifically infection, UTI, pneumonia and/or VTE at the start of the study and *Not Applicable* in studies reporting on outcomes which are not relevant preoperatively (e.g. operative duration or LoS). Outcomes were measured in a valid and reliable way for 36.4% of studies, however this was *Unclear* in 54.5% of studies. Completion of follow-up was *Not Applicable* given the retrospective nature of most studies. Appropriate statistical methods were reported by most studies (72.7%).

The case control study (32) matched controls, at minimum, on age, gender, surgical procedure and duration of follow-up, with data for matching collected from the same source population. 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 (e.g. level of obesity was measured by BMI for both groups), however a description on how the exposure was measured was not reported (e.g. methods and/or equipment used to measure the height and weight for BMI calculation). No description of how outcomes were assessed or diagnosed was reported, however both the time for follow-up time and statistical analysis were appropriate (Table 2).

2.4 Data Extraction

Data was extracted from included studies using a customised data extraction template (AT). Prior to analysis, all extracted data was checked with source articles to confirm accuracy.

Where possible, unadjusted data (number of events) was extracted and used in most of the meta-analyses for multiple reasons. First, to avoid potential heterogeneity attributable to adjustment for different confounding factors between studies (37). Secondly, 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 versus non-obese. For categorical variables, event and sample totals were summed for each BMI group of < 30.0 versus ≥ 30.0 . Conversely, for continuous variables, BMI groupings within a study could not be summed and consequently, multiple meta-analyses comparing various BMI groupings were conducted. Where various BMI categories did not align across studies, outcomes were combined in the overall meta-analysis comparing obese versus non-obese, despite variations in individual study BMI groupings. For example, Gupta et al. (28) categorised BMI as > 35.0 , not specifically > 30.0 . This approach was necessary for meta-analyses conducted for outcomes including mortality, blood transfusion, infection, and UTI. Furthermore, where possible, multiple meta-analyses using the various BMI categories were also conducted for each outcome, allowing exploration of the impact of different levels of BMI on outcome.

Some studies simply reported the percentage of outcome events, without reporting the raw number of events (26, 29). As raw figures are required for meta-analysis, they were calculated, where possible, from the data available. As these studies reported on large databases, this created a potential for error in the calculation of the raw number of events.

2.5 Data Analysis

Quantitative data, where possible, was pooled in statistical meta-analysis using Review Manager (RevMan) Version 5.3 software (38). Effect sizes with 95% confidence intervals were expressed as odds ratios (OR) for categorical data and weighted mean differences (WMD) for continuous data. A random-effects model with a Mantel-Haenszel statistical method for OR (39), and an inverse variance method for WMD were used for the meta-analyses (40). Where five or less studies were included in the analysis a fixed-effects model was preferentially employed (41). Statistical heterogeneity was assessed using both the standard Chi^2 (χ^2) and I^2 . In instances where substantial or statistically significant ($p = 0.05$) heterogeneity was observed with the fixed-effects model, sensitivity analysis was also performed using a random-effects model. Subgroup analyses were performed to explore the impact of different joint arthroplasty procedures in the upper limb shoulder arthroplasty (TSA and RTSA) and elbow arthroplasty cohorts. Sensitivity analyses were also conducted for meta-analyses heavily weighted with the findings of a single study ($> 90.0\%$). This was necessary for studies reporting on outcomes including VTE, fracture and revision. For outcomes where statistical pooling was not possible, findings are presented in narrative.

3. Results

A total of 192 104 patients were reported across included studies, a majority of which were female (61.1%; 117 471 females) and mostly 65 years of age or older. Seven studies reported on whether the obese cohort had a diabetic comorbidity. Follow-up duration varied across studies and outcomes, and ranged from a minimum of simply the inpatient duration (from hospital admission to discharge) (26), up to a maximum of over 30 years (33) (Table 1).

3.1 Effect of obesity on infection, venous thromboembolism, blood transfusion, urinary tract infection, pneumonia and mortality

Ten TSA/RTSA studies (24-26, 28-34) and one TEA study (27) evaluated the influence of obesity on infection. Classifications of infection and postoperative follow-up durations varied in each study (Table 1). Meta-analysis revealed that the odds of infection increased with increasing BMI, from 2.37 (95% CI [1.65, 3.41]) times patients who were obese, to 5.04 (95% CI [4.70, 5.39]) times patients who were morbidly obese, when compared to patients who were not obese (Fig 2.). Subgroup analyses indicated a small difference between the overall effect size compared to shoulder arthroplasty procedures (TSA and RTSA) alone (Fig 2.). This suggests that TEA patients may be at slightly greater odds of infection than shoulder arthroplasty patients, however conclusions are limited as only one TEA study was analysed. Heterogeneity between studies was moderate to substantial for each meta-analysis (Table 3), limiting plausible conclusions.

A meta-analysis revealed that the odds of VTE were 3.92 times greater TSA, RTSA and TEA patients who were obese compared to patients who were not obese (Fig 3. Panel A). Subgroup analysis identified a negligible difference between the overall effect size compared to the one TEA study alone (OR = 3.51; 95% CI [2.27, 5.41]). Although not statistically significant, substantial heterogeneity was identified between studies which limited plausible conclusions (Table 3). Consequently, a meta-analysis using a random-effects model was conducted as a sensitivity analysis which demonstrated consistent results (Table 3). TSA, RTSA and TEA patients who were morbidly obese had 5.46 times greater odds of VTE compared to patients with a BMI < 30 (Fig. 3: Panel B). The I^2 statistic identified moderate heterogeneity, however this was not statistically significant (Table 3). The heterogeneity observed may be due to a range of factors including combining studies that reported on different arthroplasty joints, types of VTE, study sites, and had differing orthopaedic surgeons. Both meta-analyses were heavily weighted with the findings from Werner et al. (34), however sensitivity analyses demonstrated similar findings (Table 3).

Results of meta-analysis using a fixed-effects model suggested that patients who were obese and receiving TSA, RTSA and TEA had 1.47 times greater odds of blood transfusion compared to patients who were not obese (Table 3). However, substantial statistical heterogeneity (I^2 , 95%) was observed between studies. A subsequent meta-analysis using a random-effects model was performed, however high statistical heterogeneity was once again observed (Table 3). Overall, the heterogeneity of meta-analyses with TSA/RTSA and TEA studies was too high to draw meaningful conclusions. A sensitivity analysis that only assessed TSA/RTSA patients using a fixed-effects model revealed that the odds of blood transfusion was 29% less in patients who were obese compared to not obese (Table 3). Employing a random-effects analysis

revealed no difference in odds of blood transfusion in TSA/RTSA patients who were obese compared to patients who were not obese.

Obesity was found to have no influence on the odds of UTI (OR = 0.88; 95% CI [0.48, 1.61] or mortality (OR = 1.79; 95% CI [0.79, 4.03]), and a single study reported no statistically significant difference on the incidence of pneumonia between BMI groups (29).

3.2 Effect of obesity on operative duration and length of stay

Operative duration was not clearly or consistently defined across studies combined in the following meta-analyses (Table 1). Obesity was found to significantly increase operative duration, with TSA/RTSA patients who were obese experiencing operations 10.00 minutes (95% CI [6.31, 13.69]) longer than patients with a BMI in the normal range. This increased to 12.48 minutes (95% CI [8.40, 16.55]) in patients with a BMI ≥ 35.0 . Heterogeneity between studies for each meta-analysis was not statistically significant (Table 3).

No statistically significant difference in LoS (days) was observed between TSA/RTSA patients who were obese and patients with a BMI in the normal or overweight range. However, TSA/RTSA patients who were morbidly obese had a small, yet statistically significant increase in LoS of 0.28 days (6.72 hours) (95% CI [0.14, 0.43]) in comparison to patients who were not obese.

4. Discussion

With increasing demand for joint arthroplasty, risk factors that predispose patients to greater complications must be thoroughly investigated. Review findings revealed greater risk of infection and VTE with increasing BMI, which is consistent with research on lower limb arthroplasty. A large systematic review on the total knee arthroplasty (TKA) population reported odds of infection ranging from 1.45 in patients who were obese, up to 4.01 in patients who were morbidly obese, when compared to patients who were not obese (41). Similarly, odds of DVT increased with increasing BMI, from 2.70 in patients who were obese to 8.19 in patients who were morbidly obese (42). Current views, such as those of Werner et al. (34) concluded that an increased risk of VTE in patients with a high BMI was ‘not surprising’ given the potential difficulty of mobilisation with increasing BMI, combined with the loss of an extremity to assist with mobilising. Antibiotic prophylaxis recommendations aim to provide weight-adjusted dosing for a number of antibiotics, however some researchers suggest that evidence for adequate dosing is not yet available (43). The majority of studies included in this review did not report on the antibiotic prophylactic regimes used. Consequently, whether weight-adjusted antibiotic dosing was used, or whether the type of antibiotic or dosing regime was uniform across studies, remains unknown. Correspondingly, there is a paucity of evidence on the use of VTE prophylaxis and the absence of universal guidelines may result in different prophylaxis regimes implemented across hospital sites. Studies reporting VTE incidence and infection rates should also describe the prophylaxis regimes used to improve comparability across studies in this field.

Conversely, obesity had no influence on the odds of UTI or mortality in upper limb arthroplasty patients. This corresponds with the results of a systematic review that found no significant difference in perioperative mortality rates across TKA obese and non-obese groups (42), however conflicts with findings from D'Apuzzo et al. (44) who observed greater odds of UTI in the TKA patient population who were obese.

Blood transfusion has been associated with several additional complications such as infection and VTE in upper limb arthroplasty patients (45). This review showed that patients who are obese have an increased likelihood of blood transfusion, however evidence presented here was heterogeneous, and effect estimates varied greatly depending on the statistical model used for synthesis. Consequently, the impact of obesity on need for blood transfusion in upper limb arthroplasty remains inconclusive.

The review findings suggest that operative duration increases by some 10 to 13 minutes, with increasing BMI for TSA and RTSA patients who were obese. This is comparable to findings in the lower limb population. Bradley et al. (46) identified a linear relationship between theatre time required for total hip and knee arthroplasty, and BMI, with a 5-point increase in BMI increasing theatre time by approximately seven minutes. In contrast, Lozano et al. (47) observed that longer surgical times were not required for TKA patients with a BMI ≥ 35.00 kg/m². On the contrary, results demonstrated little impact of obesity on LoS; patients with morbid obesity demonstrated a small increase of 6.72 hours in comparison to patients who were not obese.

Three new studies eligible for this review were published after the search was conducted (27 May, 2016) (45, 48, 49). Wagner et al. (49) presented comparable results, reporting a strong

association between BMI and superficial infection but no relationship between BMI and periprosthetic infection in a mixed shoulder arthroplasty population (TSA, RTSA and HA). Contrary to the results presented here, this study suggested no significant associations between BMI and risk of VTE, however findings were based on a small sample of patients that experienced the VTE (23 patients). Present review findings also corroborate with results from a retrospective cohort study by Anakwenze et al. (48) that found no association between high BMI and one-year mortality in TSA and RTSA patients. However, no association was found between high BMI and risk of three-year deep infection, which conflicts with the current review findings (48). The final study also presented findings similar to the results of this review, reporting no association between obesity and higher odds of blood transfusion in shoulder arthroplasty patients (45).

When considering the findings presented in this review, there are several limitations worth noting. Firstly, little information and consistency in the definition of operative duration was provided across the included studies. Jiang et al. (29) reported the '*total operation time in minutes*', while Beck et al. (24) described this outcome as '*surgery time (min)*'. Both Chalmers et al. (25) and Gupta et al. (28) simply reported '*length of procedure in minutes*'. Further detail was provided by Pappou et al. (32) who defined operative duration as '*incision to dressing*', and Li et al. (30) who stated surgical time was from '*incision to closure as documented by the anesthesia records*'. Secondly, findings relating to infection and VTE are also limited, given prophylactic regimes were not standardised across the included studies.

Thirdly, there are several patient and surgical factors that have potential to influence the findings. Evidence suggests that operative duration is affected by additional patient factors such as gender, primary indication and surgical history of the affected shoulder (50).

Furthermore, younger age, male gender and traumatic arthroplasty have been found to increase risk of infection (51). Fourthly, 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 the measure has several well-acknowledged shortcomings (52).

The review process also imposed several limitations. Firstly, the comprehensive search strategy, with no 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 one 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 for errors in data handling. Finally, whilst the use of unadjusted data provided several advantages for data analysis, it leaves findings susceptible to other confounders such as age, gender or comorbidity which could not be accounted for.

4.1 Conclusions

Findings for meta-analyses revealed that obesity increased the odds of infection and VTE following upper limb arthroplasty. Greater operative duration was also found for TSA and RTSA patients with increasing BMI. Obesity had no impact on the odds of UTI or mortality when compared to counterparts who were not obese or of normal weight. Furthermore, the

367 effect of obesity on the incidence of blood transfusion was inconclusive and minimal evidence
368 was available for pneumonia.
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370 Surgeons should consider advising patients who are obese of the greater risk of complications
371 identified when considering elective upper limb arthroplasty. Alternative treatment options, or
372 further precautionary measures, such as using adjusted prophylaxis regimes, should be
373 considered when treating arthroplasty patients who are obese. Further knowledge of the
374 additional risks associated with pre-existing obesity allows the patient and surgeon to make a
375 shared and well-informed decision regarding whether the benefits of upper limb arthroplasty
376 outweigh the potential risk of complications prior to proceeding with surgery. However,
377 noteworthy limitations surrounded the lack of information regarding prophylaxis regimes and
378 BMI measurement tools used in included studies. Researchers should endeavour to report such
379 information to improve comparability and increase confidence in outcome comparisons across
380 studies in the future.

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6. Figures

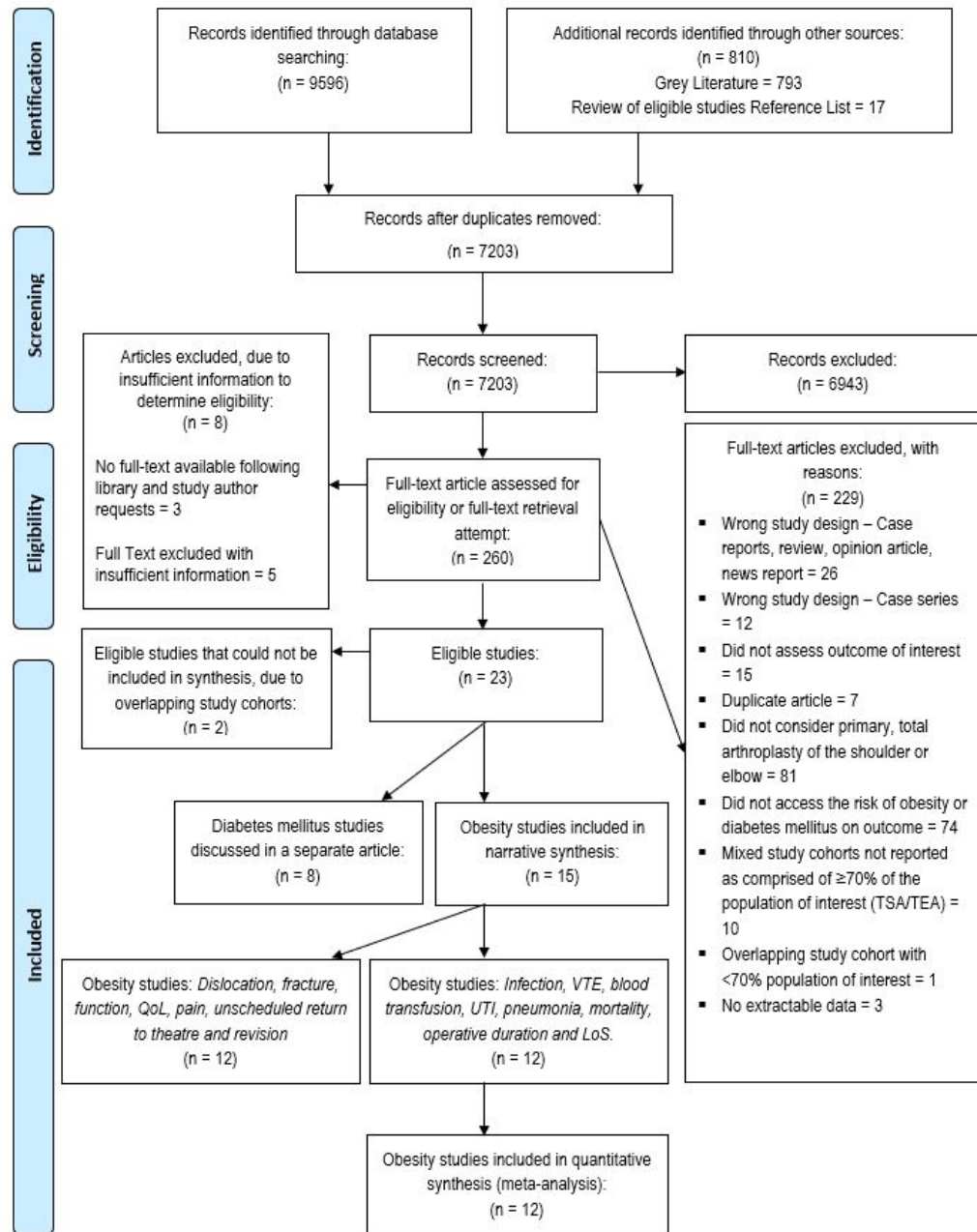
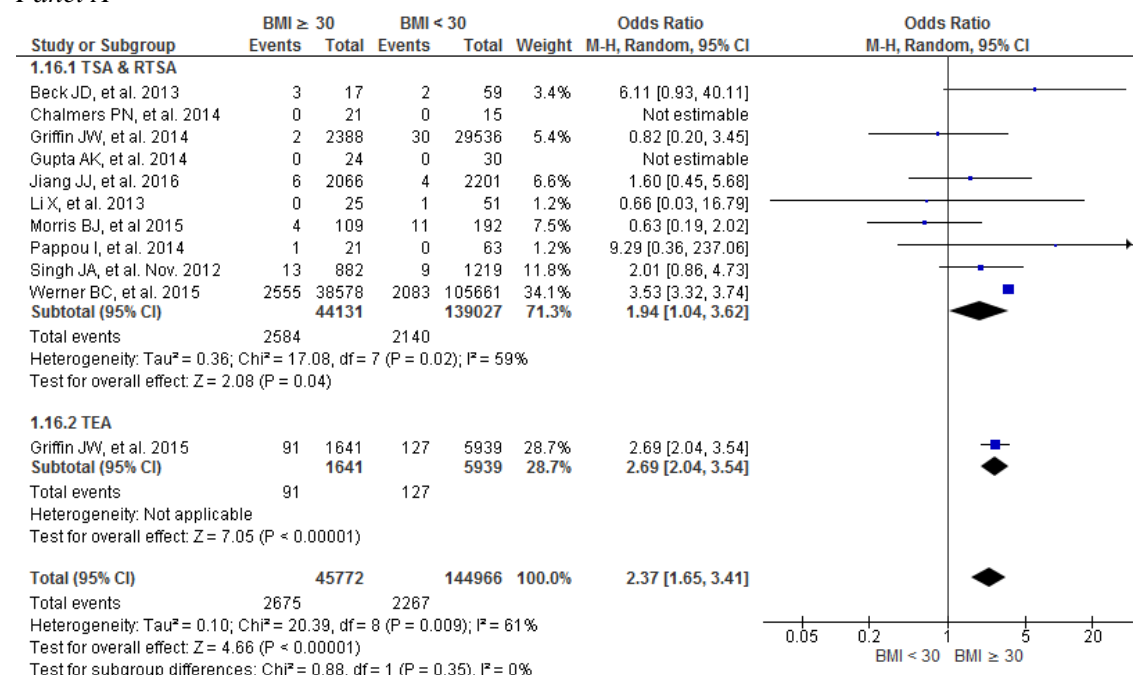


Fig 1. PRISMA Flow diagram outlining process of study selection and inclusion. *

* Two studies reported on both obesity and diabetes mellitus, that is, a total of 21 unique studies identified prior to breakdown by exposure.

LoS = Length of Stay; QoL = Quality of Life; UTI = Urinary Tract Infection; VTE = Venous Thromboembolism

Panel A



Panel B

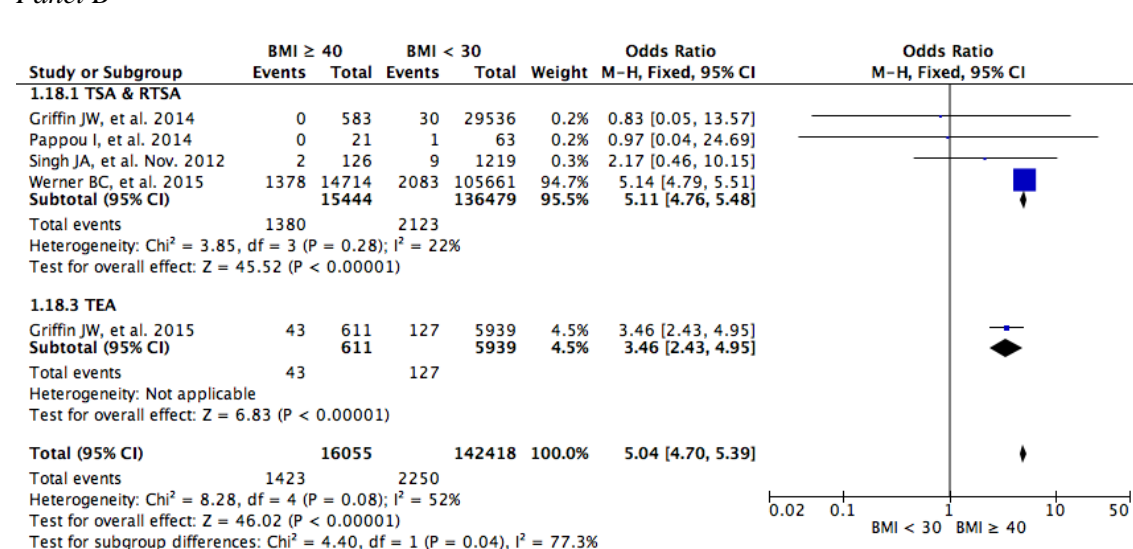
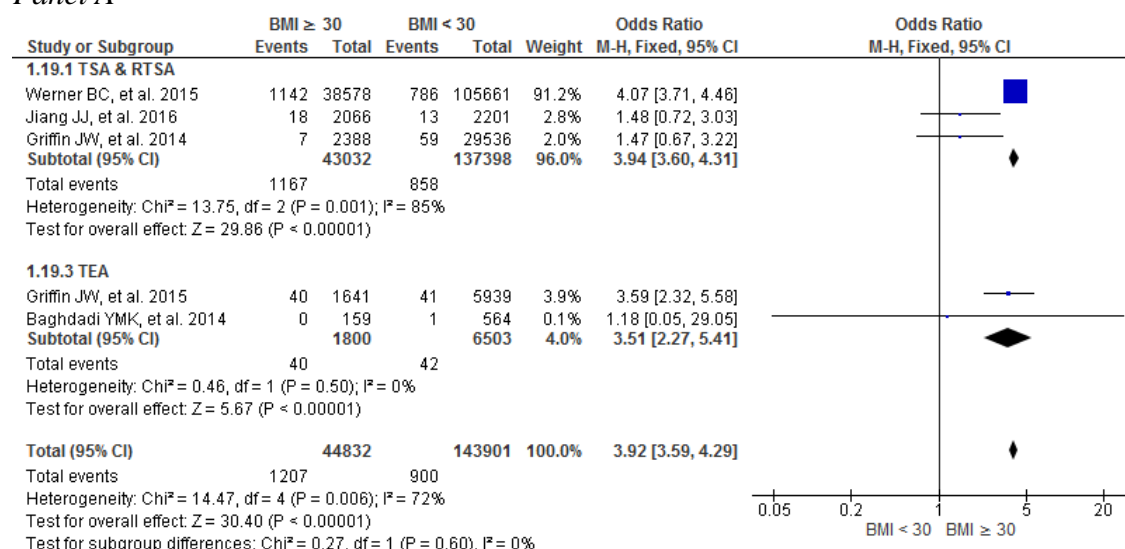


Fig 2. Forest plots of the odds of infection in various BMI groups. Follow-up periods: inpatient duration, up to 30 days, within 1 year, minimum 1 year, up to 90 days, minimum 90 days, up to 2 years, minimum 2 years, and a mean follow-up of 7 years (SD = 6 years). (M-H: Mantel-Haenszel; CI: confidence interval; df: degrees of freedom).

Panel A: Forest plot of the odds of infection upper limb arthroplasty patients with a BMI ≥ 30.0 versus BMI < 30.0. Subgroup analysis was conducted for periprosthetic infection, and arthroplasty joint type (total shoulder arthroplasty [TSA] and reverse total shoulder arthroplasty [RTSA], or total elbow arthroplasty [TEA]) (random-effects model).

Panel B: Fixed-effects model: TSA/RTSA and TEA patients who were morbidly obese (BMI ≥ 40.0) versus non-obese (BMI < 30.0). Subgroup analysis was conducted for arthroplasty joint type (TSA and RTSA, or TEA).

Panel A



Panel B

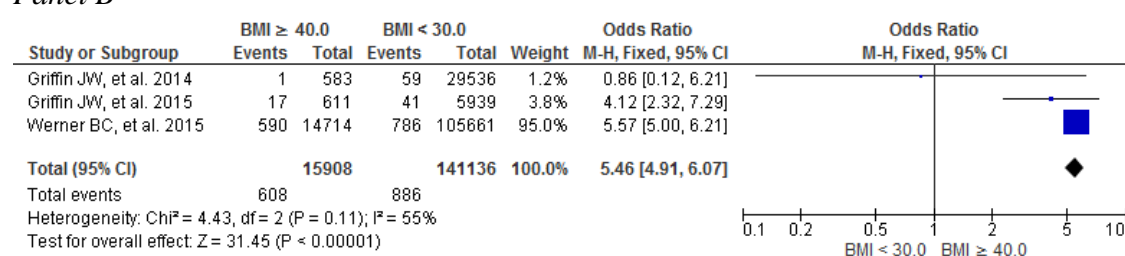


Fig 3. Forest plot of the odds of venous thromboembolism (VTE) in various BMI groups. Follow-up periods: inpatient duration, up to 30 days, up to 90 days and a median follow-up duration of 5.8 years (range: 0 – 25 years). (M-H: Mantel-Haenszel; CI: confidence interval; df: degrees of freedom; IV: inverse variance).

Panel A: Fixed-effects model: Total shoulder arthroplasty (TSA), reverse total shoulder arthroplasty (RTSA) and total elbow arthroplasty (TEA) patients who were obese (BMI ≥ 30.0) versus non-obese (BMI < 30.0). Subgroup analysis was conducted for arthroplasty joint type (TSA/RTSA, or TEA).

Panel B: TSA/RTSA and TEA patients who were morbidly obese (BMI ≥ 40.0) versus non-obese (BMI < 30.0)

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Table 1. Summary of characteristics of included studies

Included study	Methods	Exposure, Arthroplasty procedure	Participants	Setting	Complications and postoperative outcomes	
Jiang et al. (29)	Study design: Retrospective cohort study Follow-up: Up to 30 days Country of origin: USA No. of surgeons performing procedure: Not reported Surgical technique: Not reported	Exposure: 1. BMI = 18.5-25 2. BMI = 25-30 3. BMI = 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. $n = 940$ Demographics: <i>Age: average yr. (SD)</i> 1. 72 (11) 2. 71 (10) 3. 69 (10) 4. 67 (9) <i>Gender: (F: M)</i> 1. 494: 244 2. 717: 746 3. 574: 552 4. 583: 357 <i>Ethnicity/Nationality:</i>	Setting: The American College of Surgeons National Surgical Quality Improvement Program database was analysed from 2006 to 2013 for all patients who underwent a primary TSA, including anatomic TSA and reverse TSA. Exclusions: Patients were excluded if they had a BMI less than 18.5 kg/m ² , lacked documented preoperative height and weight, or had previous shoulder hardware, fracture, pathologic fracture,	LoS: Days (SD) 1. 2.1 (1.4) 2. 2.1 (2.9) 3. 2.0 (1.2) 4. 2.1 (1.2) Blood transfusion: n (%) 1. 44.3 (6) 2. 52.7 (3.6) 3. 40.5 (3.6) 4. 21.6 (2.3) <i>Adjusted RR (95% CI); P-Val</i> 2. 0.68 (0.33–1.41); 0.300 3. 0.82 (0.39–1.71) 0.591 4. 0.41 (0.16–1.05) 0.063 Operative duration (Min): Defined as: 'total operation time in minutes'. Mean (SD)	Pneumonia: n (%) 1. 2.95 (0.4) 2. 7.3 (0.5) 3. 6.8 (0.6) 4. 1.88 (0.2) UTI: n (%) 1. 11.1 (1.5) 2. 11.7 (0.8) 3. 6.8 (0.6) 4. 12.2 (1.3) DVT: n (%) 1. 5.2 (0.7) 2. 1.46 (0.1) 3. 3.4 (0.3) 4. 6.6 (0.7) PE: n (%) 1. 3.7 (0.5) 2. 2.9 (0.2) 3. 4.5 (0.4)

			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 <i>DM comorbidity: n (%)</i> 1. 59.0 (8) 2. 175.6 (12) 3. 132.8 (18) 4. 253.8 (27)	tumour, or associated infection.	1. 110 (42) 2. 115 (46) 3. 120 (43) 4. 122 (45) Superficial infection: n (%) 1. 0.0 (0.0) 2. 1.46 (0.1) 3. 3.4 (0.3) 4. 1.9 (0.2)	4. 3.8 (0.4) Mortality: n (%) 1. 0.0 (0) 2. 1.46 (0.1) 3. 3.4 (0.3) 4. 1.88 (0.2) Deep infection: n (%) 1. 0.7 (0.1) 2. 1.46 (0.1) 3. 1.1 (0.1) 4. 0.0 (0.0)
Werner et al. (34)	Study design: Retrospective cohort study	Exposure: 1. Non-obese (BMI < 30) 2. Obese	Sample size: Total <i>n</i> = 144 239 1. <i>n</i> = 105 661 2. <i>n</i> = 23 864 3. <i>n</i> = 13 759	Setting: Patients who underwent TSA or RTSA from 2005 to 2012 were identified by	Infection (1 Yr.): n (%) 1. 2083 (2.0) 2. 1177 (4.9) 3. 1284 (9.3) 4. 94 (9.8)	Medical complications (90 Days): n (%) 1. 4295 (4.1) 2. 2967 (12.4) 3. 2630 (19.1)

	<p>Follow-up: Infection, dislocation, component loosening, periprosthetic fracture = 1 year.</p> <p>Revision TSA = up to 8 years.</p> <p>VTE = 90 days medical complications</p> <p>Country of origin: USA</p> <p>No. of surgeons performing procedure: Not reported</p>	<p>(BMI = 30-39.9)</p> <p>3. Morbidly obese (BMI = 40-49.9)</p> <p>4. Super obese (BMI => 50)</p> <p>Procedure: TSA and RTSA</p> <p>Indication for procedure: Not reported</p>	<p>4. n = 955</p> <p>Demographics: <i>Age: (%)</i> < 65 Years</p> <p>1. 6.4 2. 7.8 3. 15.4 4. 27.1</p> <p>65 – 80 Years</p> <p>1. 68.6 2. 76.9 3. 74.7 4. 68.4</p> <p>> 80 Years</p> <p>1. 25.0 2. 15.2 3. 9.9 4. 4.5</p> <p><i>Gender: (F: M): n (%)</i></p> <p>1. 62763 (59.4): 42898 (40.6) 2. 15130 (63.4): 8734 (36.6) 3. 9893 (71.9): 3866 (28.1)</p>	<p>ICD-9 procedure codes: 81.80 and 81.88.</p> <p>Patient data was collected from the PearlDiver patient records database.</p> <p>Exclusions: No patients undergoing shoulder HA were included.</p>	<p><i>OR (95% CI); P-Val</i> 4 vs 1: 3.4 (2.6–4.4); <.0001 4 vs 2: 2.3 (1.8–3.0); <.0001 4 vs 3: 1.7 (1.3–2.2); <.0001</p> <p>VTE (90 Days): n (%)</p> <p>1. 786 (0.7) 2. 552 (2.3) 3. 543 (3.9) 4. 47 (4.9)</p> <p><i>OR (95% CI); P-Val</i> 4 vs 1: 2.9 (1.8–4.5); <.0001 4 vs 2: 1.9 (1.2–3.0); .008 4 vs 3: 1.4 (0.9–2.2); .189</p>	<p>4. 271 (28.4)</p> <p><i>OR (95% CI); P-Val</i> 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</p>
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	Surgical technique: Not reported		4. 801 (83.9): 154 (16.1) <i>Ethnicity/Nationality:</i> Not reported <i>DM comorbidity: n (%)</i> 1. 29662.6 (28.1) 2. 11454.7 (48.0) 3. 8379.2 (60.9) 4. 660.9 (69.2)			
Morris et al. (31)	Study design: Retrospective cohort study Follow-up: minimum 1-year follow-up Country of origin: USA	Exposure: 1. DM 2. No DM 3. Healthy weight BMI < 25 4. Overweight BMI 25 - 30 5. Obese BMI > 30 Procedure: RTSA	Sample size: Total <i>n</i> = 301 1. <i>n</i> = 48 2. <i>n</i> = 253 3. <i>n</i> = 96 4. <i>n</i> = 96 5. <i>n</i> = 109 Demographics: <i>Age:</i> Mean (SD) Total: 68.3 (11.3) <i>Gender (F: M): n (%)</i>	Setting: RTSAs completed by a single surgeon from 2004 to 2011, in a prospectively collected shoulder arthroplasty registry. Exclusions: All patients with a history of infection in the operative shoulder and all patients undergoing revision of an existing RTSA were excluded.	Periprosthetic infection: <i>n (%)</i> 1. 3 (6.3) <i>OR (95% CI); P-Val</i> 1. 1.34 (0.23–5.23); .877 3. 6 (6.3) 4. 5 (5.2) 5. 4 (3.7)	

	<p>No. of surgeons performing procedure: 1</p> <p>Surgical technique: Standard deltopectoral approach using the Aequalis RSA system (Tornier, Inc., Bloomington, MN, USA).</p> <p>Non-antibiotic-loaded Cemented humeral stems were used.</p>	<p>Indication for procedure: RC tear arthropathies: 144 (47.8%)</p> <p>Failed prior arthroplasties: 61 (20.3%)</p> <p>Acute PH fracture: 22 (7.3%)</p> <p>PH non-union/malunions: 24 (8.0%)</p> <p>OA: 18 (6.0%)</p> <p>Instability arthropathies: 10 (3.3%)</p> <p>Inflammatory arthropathies: 6 (2.0%)</p> <p>Others: 16 (5.3%).</p>	<p>Total 179 (59.5): 122 (40.5)</p> <p><i>Ethnicity/Nationality:</i> Not reported</p>			
Griffin et al. (27)	<p>Study design: Retrospective cohort study</p>	<p>Exposure:</p> <p>1. Non-obese (BMI < 30)</p> <p>2. Obese</p>	<p>Sample size:</p> <p>Total $n = 7580$</p> <p>1. $n = 5939$</p> <p>2. $n = 1030$</p> <p>3. $n = 611$</p>	<p>Setting:</p> <p>Data was derived from the Medicare database within the PearlDiver records, screened from 2005 to</p>	<p>Infection (90 Days): n (%)</p> <p>1. 127 (2.1)</p> <p>2. 48 (4.7)</p> <p>3. 43 (7.9)</p>	

	<p>Follow-up: Up to 90 Days; 1 Yr.; 2 Yrs.</p> <p>Country of origin: USA</p> <p>No. of surgeons performing procedure: Not reported</p> <p>Surgical technique: Not reported</p>	<p>(BMI = 30-40)</p> <p>3. Morbidly Obese (BMI > 40)</p> <p>Procedure: TEA</p> <p>Indication for procedure: Not reported</p>	<p>Demographics: <i>Age: (%)</i> < 65 Years 1. 17.2 2. 18.7 3. 26.5 65 – 80 Years 1. 53.5 2. 65.1 3. 63.7 > 80 Years 1. 29.3 2. 16.1 3. 9.8</p> <p><i>Gender (F: M): n (%)</i> 1. 4781 (80.5): 1158 (19.5) 2. 859 (83.4): 171 (16.6) 3. 527 (86.3): 84 (13.7)</p> <p><i>Ethnicity/Nationality:</i> Not reported</p>	<p>2011, using CPT and ICD-9 codes.</p> <p>Exclusions: Patients who underwent surgery for revision TEA were excluded, but patients with revision for fracture were included.</p>	<p><i>OR (95% CI); P-Val</i> Obese vs non-obese 2.2 (1.6–3.1); <.0001 Morbidly obese vs non-obese 3.5 (2.4-4.9); <.0001 Morbidly obese vs obese 1.5 (1.0 – 2.4); .042</p> <p>VTE (90 Days): n (%) 1. 41 (0.7) 2. 23 (2.2) 3. 17 (2.8) <i>OR (95% CI); P-Val</i> Obese vs non-obese 3.3 (2.0–5.5); <.0001 Morbidly obese vs non-obese 4.1 (2.3–7.3); <.0001 Morbidly obese vs obese 1.3 (0.7–2.4); .0485</p> <p>Blood transfusion: n (%) 1. 62 (1.0) 2. 33 (3.2) 3. 37 (6.1) <i>OR (95% CI); P-Val</i> Obese vs non-obese</p>	
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			DM comorbidity: n (%) 1. 1906.4 (32.1) 2. 532.5 (51.7) 3. 408.1 (66.8)		3.1 (2.0–4.8); <.0001 Morbidly obese vs non-obese 6.1 (4.0–9.3); <.0001 Morbidly obese vs obese 1.9 (1.2–3.1); .006	
Gupta et al. (28)	Study design: Retrospective cohort study Follow-up: Minimum 90 days Country of origin: USA No. of surgeons performing procedure: Not reported	Exposure: 1. Normal BMI (BMI < 25) 2. Class 1 obesity (BMI = 25 – 35) 3. Class 2 Obesity (BMI > 35) Procedure: RTSA Indication for procedure: RC tear arthropathy: 45	Sample size: Total <i>n</i> = 119 1. <i>n</i> = 30 2. <i>n</i> = 65 3. <i>n</i> = 24 Demographics: Age: Mean (SD) Total: 73.3 (9.8) 1. 75.7 (8.2) 2. 74.1 (9.8) 3. 68.4 (10.5) Gender (<i>F: M</i>): <i>n</i> (%) Total: 76 (64): 43 (36) 1. 22 (73): 8 (27) 2. 37 (57): 28 (43) 3. 18 (75): 6 (25)	Setting: Patients who had undergone primary RTSA with a minimum 90-day postoperative follow-up were included. Department of Orthopedic Surgery, Rush University Medical Center, Chicago, IL, USA. Exclusions: Patients with previous shoulder arthroplasty, if RTSA was performed as a revision for a failed prior arthroplasty (hemiarthroplasty or TSA),	Operative duration (Min): Defined as: ' <i>length of procedure in minutes</i> '. Mean (SD) 1. 98 (41) 2. 96 (43) 3. 120 (29) Blood transfusion: n (%) 1. 1 (3.3) 2. 2 (3.1) 3. 3 (12.5)	Mortality: n (%) 1. 0 (0) 2. 0 (0) 3. 0 (0) Superficial wound infection: n (%) 1. 0 (0) 2. 1 (1.5) 3. 0 (0)

	Surgical technique: Not reported	massive/ irreparable RC tear: 19 End-stage GH arthritis with irreparable RC tear: 35 Inflammatory arthropathy: 6 PH malunion with associated irreparable RC tear: 12	<i>Ethnicity/Nationality:</i> Not reported <i>DM comorbidity:</i> Authors reported DM comorbidity for all patients that had a complication of interest. Of the outcomes of interest in this review, 1 patient with a BMI > 40.0 experienced a dislocation.	prior deep space infection requiring explantation, or incomplete records.		
Griffin et al. (26)	Study design: Retrospective cohort study Follow-up: Inpatient duration Country of origin:	Exposure: 1. Non-obese (BMI ≤ 29) 2. Obese (BMI = 30 – 39) 3. Morbidly obese (BMI: ≥ 40)	Sample size: Total <i>n</i> = 31 924 1. <i>n</i> = 29 536 2. <i>n</i> = 1805 3. <i>n</i> = 583 Demographics: <i>Age:</i> Mean (SD) Total: 68.7 (10.8) 1. 68.3 (10.9) 2. 66.8 (9.2)	Setting: The NIS database was used to identify in-hospital data on 39,924 patients who underwent TSA in the US between 1 January, 1998 and 31 December, 2008. CPT and ICD-9 codes were used.	LoS: Days (SD) Total: 2.57 (1.98) 1. 2.56 (2.0) 2. 2.54 (1.67) 3. 2.84 (1.77) Mortality: n (%) Total: 31.9 (0.1) 1. 29.5 (0.1) 2. 1.8 (0.1) 3. 1.2 (0.2)	Infection: n (%) Total: 31.9 (0.1) 1. 29.5 (0.1) 2. 1.8 (0.1) 3. 0.0 (0.0) PE: n (%) Total: 63.8 (0.2) 1. 59.1 (0.2) 2. 5.4 (0.3) 3. 1.2 (0.2)

	<p>USA</p> <p>No. of surgeons performing procedure: Not reported</p> <p>Surgical technique: Not reported</p>	<p>Procedure: TSA</p> <p>Indication for procedure: Not reported</p>	<p>3. 64.9 (9.1)</p> <p><i>Gender (F: M): n (%)</i> Total: 17973 (56.3): 13951 (43.7) 1. 16392 (55.5): 13144 (44.5) 2. 1170 (64.8): 635 (35.2) 3. 399 (68.4): 184 (31.6)</p> <p><i>Ethnicity/Nationality:</i> <i>White (%)</i>: Total: 91.1 1. 91.5 2. 86.3 3. 83.9</p> <p><i>Black (%)</i>: Total: 3.9 1. 3.6 2. 6.8 3. 10.1</p> <p><i>Other (%)</i>: Total: 5.0</p>	<p>Exclusions: None reported</p>		
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			1. 4.9 2. 6.9 3. 6.0 <i>DM comorbidity:</i> Not reported			
Chalmers et al. (25)	Study design: Retrospective cohort study Follow-up: Minimum 90 days Country of origin: USA No. of surgeons performing procedure: 1 Surgical technique: Not reported	Exposure: 1. Normal BMI: (BMI < 25) 2. Obesity class I: (BMI: 25-35) 3. Obesity class II: (BMI: > 35.0) Procedure: TSA Indication for procedure: n OA: 120	Sample size: Total <i>n</i> = 127 1. 15 2. 91 3. 21 Demographics: Age: Mean 1. 66.3 2. 65.8 3. 65.2 <i>Gender (F: M): n (%)</i> 1. 10 (67): 5 (33) 2. 36 (40): 55 (60) 3. 13 (62): 8 (38) <i>Ethnicity/Nationality:</i> Not reported	Setting: All patients who underwent TSA by the senior author with a minimum of 90-days of post-operative follow-up. Department of Orthopedic Surgery, Rush University Medical Center, Chicago, Illinois Exclusions: History of prior ipsilateral shoulder arthroplasty, or incomplete peri- or post-operative records.	Operative duration (Min): Defined as: ' <i>length of procedure in minutes</i> '. Mean 1. 112 2. 111 3. 120 Blood transfusion: n (%) 1. 0 (0.0) 2. 2 (2.2) 3. 1 (4.7)	Infection: n (%) 1. 0 (0.0) 2. 0 (0.0) 3. 0 (0.0) Mortality: n (%) 1. 0 (0.0) 2. 0 (0.0) 3. 0 (0.0)

		Post-traumatic arthropathy: 4 Instability related arthropathy: 3	<i>DM comorbidity:</i> Not reported			
Baghdadi et al. (23)	Study design: Retrospective cohort study Follow-up: Median: 5.8 years, range: 0 - 25 years Country of origin: USA No. of surgeons performing procedure: Not reported, but majority (76%)	Exposure: 1. Non-obese (BMI < 30) 2. Obese: (BMI ≥ 30) Procedure: TEA Indication for procedure: n Inflammatory conditions: 317 Traumatic conditions: 310 Primary osteoarthritis: 19	Sample size: Total <i>n</i> = 723 1. 564 2. 159 Demographics: <i>Age:</i> Mean *(SD) 62.3 (13.7) <i>Gender (F: M):</i> n (%) 550 (76): 173 (24) <i>Ethnicity/Nationality:</i> Not reported <i>DM comorbidity:</i> Not reported	Setting: Patients who underwent primary TEA using a single implant design (semi-constrained, linked TEAs using the Coonrad/Morrey Total Elbow ([Zimmer, Warsaw, Indiana]) performed between 1987 and 2006. Exclusions: None reported	Thromboembolic events: n (%) 1. 1 (0.2) 2. 0 (0.0)	Perioperative mortality (90 Days): n (%) 1. 3 (0.5) 2. 2 (1.3)

	<p>performed by a single surgeon</p> <p>Surgical technique: 722 cementless 1 cemented Single Prosthesis: Coonrad/Morrey Total Elbow (Zimmer, Warsaw, Indiana) Tourniquet applied</p>	<p>Resection of neoplastic lesion: 6</p> <p>Hemophilic, septic, charcot neuropathic & crystal deposition arthropathy: 10</p>				
Li et al. (30)	<p>Study design: Prospective cohort study</p> <p>Follow-up: Up to 2 years</p>	<p>Exposure: 1. Normal (BMI < 25) 2. Overweight: (BMI: 25 – 29.9) 3. Obese: (BMI ≥ 30)</p>	<p>Sample size: Total $n = 76$ 1. 26 2. 25 3. 25</p> <p>Demographics: Age: Mean (SD) 1. 71 (9)</p>	<p>Setting: Patients had unconstrained anatomic TSA in a single hospital between 1 January, 2009 and 31 January, 2010 were enrolled into the prospective total shoulder registry, grouped</p>	<p>LoS: Days (SD) 1. 2.3 (0.8) 2. 2.5 (1.5) 3. 2.4 (0.8)</p> <p>Blood transfusion: Units of blood; Mean (SD) 1. 0.2 (0.5) 2. 0.2 (0.5)</p>	<p>Operative duration (Min): Defined as: 'incision to closure as documented by the anesthesia records' Mean (SD) 1. 108.3 (19.5) 2. 115.5 (37.3) 3. 119.7 (37.3)</p>

	Country origin: USA No. of surgeons performing procedure: Multiple Surgical technique: Unconstrained anatomic TSA	Procedure: TSA Indication for procedure: OA, RA, or posttraumatic arthritis	2. 71 (11) 3. 68 (8) <i>Gender (F: M): n</i> Total: 49: 27 1. 17: 9 2. 15: 10 3. 18: 8 <i>Ethnicity/Nationality:</i> Not reported <i>DM comorbidity:</i> Not reported	according to BMI, and followed prospectively for two years Exclusions: Patients had undergone a hemiarthroplasty, RSA or any revision surgery as the index procedure.	3. 0.1 (0.4)	
Beck et al. (24)	Study design: Retrospective cohort study Follow-up: Minimum 2 years Country of origin: USA	Exposure: 1. Normal (BMI: 18.5 – 24.9) 2. Overweight: (BMI: 25 – 29.9) 3. Obese: (BMI ≥ 30) Procedure: RTSA	Sample size: Total n = 76 1. 23 2. 36 3. 17 Demographics: <i>Age:</i> Mean (range) Total: 75 (51 – 88) <i>Gender (F: M): n</i> 1. 13: 10 2. 19: 17 3. 12: 5	Setting: Patients undergoing RTSA for rotator cuff arthropathy by a single surgeon from 1 January, 2005 to 1 March, 2010. Inclusion criteria included patient age > 18 years, primary diagnosis of RC arthropathy, minimum 2-year follow-up, and subsequent RTSA by the senior author (G.D.H.). Exclusions:	Infection: n (%) 1. 0 (0.0) 2. 2 (5.6) 3. 3 (17.6) LoS: Days (SD) 1. 2.7 (1) 2. 2.6 (1) 3. 3.9 (4)	Operative duration (Min): Defined as: 'surgery time'. Mean (SD) 1. 74 (19) 2. 81 (18) 3. 83 (24)

	<p>No. of surgeons performing procedure: 1</p> <p>Surgical technique: Deltoid-splitting approach; Deltopectoral approach.</p>	<p>Indication for procedure: RC arthropathy</p>	<p><i>Ethnicity/Nationality:</i> Not reported</p> <p><i>DM comorbidity: n (%)</i> 1. 1 (4.3) 2. 7 (19.4) 3. 8 (47.1)</p>	<p>Patients with history of infection.</p>		
Singh et al. (33)	<p>Study design: Retrospective cohort study</p> <p>Follow-up: Mean: 7 Yrs. SD = 6 Yrs. Range: (1 day to 31 Years)</p> <p>Country of origin: USA</p>	<p>Exposure: 1. BMI < 24.9 2. BMI 25 – 29.9 3. BMI 30 – 34.9 4. BMI 35 – 39.9 5. BMI ≥ 40 6. No DM 7. DM</p> <p>Procedure: TSA</p> <p>Indication for procedure: RA,</p>	<p>Sample size: Total <i>n</i> = 2588 Total with known BMI: <i>n</i> = 2101 1. 475 2. 744 3. 521 4. 235 5. 126 6. 2409 7. 179</p> <p>Demographics:</p>	<p>Setting: Every adult aged 18 years or older with primary TSA performed at the Mayo Clinic Medical Center, Rochester, in a 33-year period from 1976 to 2008.</p> <p>Exclusions: None reported</p>	<p>Deep / Periprosthetic infection: <i>n</i> (%); HR (95% CI) 1. 4 (0.8); 1.0 (Reference) 2. 5 (0.7); 0.82 (0.22-3.02) 3. 7 (1.3); 1.67 (0.47-5.95) 4. 4 (1.7); 2.48 (0.63-9.83) 5. 2 (1.6); 2.46 (0.45-13.34) 6. 29 (1.2) 7. 3 (1.7)</p>	

	<p>No. of surgeons performing procedure: Not reported</p> <p>Surgical technique: Cemented and cementless fixation</p>	OA, trauma, tumour, RC disease, other	<p><i>Age: Mean (SD)</i> Total: 65 (12)</p> <p><i>Gender (F: M): n</i> 1352: 1236</p> <p><i>Ethnicity/Nationality:</i> Not reported</p> <p><i>DM comorbidity: %</i> With infection: 9.4 Without infection: 6.9</p>			
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Pappou et al. (32)	<p>Study design: Case-control Study</p> <p>Follow-up: Minimum 2 years</p> <p>Country of origin: USA</p> <p>No. of surgeons performing procedure: 1</p> <p>Surgical technique: Prosthesis: Reverse shoulder prosthesis (DJO Surgical)</p>	<p>Exposure: 1. Obese (BMI ≥ 40) 2. Controls (BMI < 30)</p> <p>Procedure: RTSA</p> <p>Indication for procedure: RC tear arthropathy = 68 Massive RC tear = 8 RA = 8</p>	<p>Sample size: Total $n = 84$ 1. 21 2. 63</p> <p>Demographics: <i>Age:</i> Mean (range) 1. 69.2 (7.1) 2. 71.1 (6.4)</p> <p><i>Gender (F: M):</i> n 1. 17: 4 2. 50: 13</p> <p><i>Ethnicity/Nationality:</i> Not reported</p> <p><i>DM comorbidity:</i> Not reported</p>	<p>Setting: A prospective database was retrospectively searched for morbidly obese patients with a BMI of ≥ 40 kg/m² who had undergone primary RTSA for a reason other than fracture from 1 January, 2003 to 31 December, 2010. Three controls for each morbidly obese patient were matched on the basis of age, sex, surgical indication, and duration of follow-up.</p> <p>Exclusions: Patients receiving a RTSA for treatment of a PH fracture, who had incomplete clinical and radiographic data, or less than 2-year follow-up.</p>	<p>Operative duration (Min): Defined as: 'incision to dressing'. 1. 118 (35) 2. 109 (35)</p> <p>LoS: Days (SD) 1. 3.1 (2.6) 2. 2.6 (1.3)</p>	<p>Superficial wound infection: n (%) 1. 1 (4.8) 2. 0 (0.0)</p> <p>UTI: n (%) 1. 0 (0.0) 2. 1 (1.6)</p>
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	All received deltopectoral approach.					
<p><i>BMI = Body Mass Index kg/m²; DVT = deep vein thrombosis; F = Female; GH = Glenohumeral; HR = hazard ratio; HA = Hemi-arthroplasty; ICD-9 = International Classification of Diseases, Ninth Revision codes; LoS = length of stay; M = Male; Min = minutes; NIS = Nationwide Inpatient Sample; n = number of arthroplasties; OA = osteoarthritis; OR = odds ratio; PE = pulmonary embolism; PH = proximal humeral; P-Val = P-Value; RA = rheumatoid arthritis; RC = rotator cuff; RR = relative risk; RTSA = reverse total shoulder arthroplasty;; SD = standard deviation; TEA = total elbow arthroplasty; TSA = total shoulder arthroplasty; USA = United States of America; UTI = urinary tract infection; Yr. = Year.</i></p>						

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Table 2. Assessment of Methodological Quality

Included Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
Cohort study designs											
Jiang et al. (29)	Y	Y	N	Y	Y	U	Y	Y	NA	NA	Y
Werner et al. (34)	Y	Y	N	Y	N	U	U	Y	NA	NA	N
Morris et al. (31)	Y	Y	Y	Y	Y	U	Y	Y	NA	NA	Y
Griffin et al. (27)	Y	Y	N	Y	N	U	U	Y	NA	NA	N
Gupta et al. (28)	N	Y	N	Y	Y	U	N	Y	NA	NA	Y
Griffin et al. (26)	Y	Y	N	Y	Y	U	U	Y	NA	NA	Y
Chalmers et al. (25)	Y	Y	N	Y	Y	U	U	Y	NA	NA	Y
Baghdadi et al. (23)	Y	Y	N	U	Y	U	U	Y	NA	NA	Y
Li et al. (30)	Y	Y	N	Y	N	NA	U	Y	U	U	N
Beck et al. (24)	Y	Y	N	Y	Y	U	Y	Y	NA	NA	Y
Singh et al. (33)	Y	Y	Y	Y	Y	NA	Y	Y	NA	NA	Y

<i>Total Y Score (%)</i>	90.9	100.0	18.2	90.9	72.7	0.0	36.4	100.0	0.0	0.0	72.7
<i>Total N Score (%)</i>	9.1	0.0	81.8	0.0	27.3	0.0	9.1	0.0	0.0	0.0	27.3
<i>Total U Score (%)</i>	0.0	0.0	0.0	9.1	0.0	81.8	54.5	0.0	9.1	9.1	0.0
<i>Total NA Score (%)</i>	0.0	0.0	0.0	0.0	0.0	18.2	0.0	0.0	90.9	90.9	0.0
Case – Control study design											
Pappou et al. (32)	Y	Y	Y	N	Y	Y	NA	N	Y	Y	-

Total columns contain the percentage of cohort studies graded as Yes (Y), No (N), Unclear (U) or Not Applicable (NA) for each critical appraisal question. Cohort and case-control studies are reported separately.

Appraisal questions for cohort studies:

(1) Were the groups similar and recruited from the same population? (2) Were the variables (exposures/ outcomes) measured similarly to assign people to both exposed and unexposed groups? (3) Was the exposure/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/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 to loss to follow-up described and explored? (10) Were strategies to address incomplete follow-up utilized? (11) Was appropriate statistical analysis used?

Appraisal questions for case-control studies:

(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?

Table 3. Meta-analysis summary table

Outcome	Studies (n)	Total Patients (n)	Events	Heterogeneity (I², %)	Statistical Method	Effect Estimate	P- Value
Infection (ALL)* Obese Vs. Non-obese	11	190 738	4942	61	OR (M – H, Random , 95% CI)	2.37; [1.65, 3.41]	< 0.00001
Periprosthetic Infection* Obese Vs. Non-obese	2	2404	37	59	OR (M – H, Fixed, 95% CI)	1.31; [0.68, 2.55]	0.42
Infection* Obese Vs. Normal	4	4406	37	25	OR (M – H, Fixed, 95% CI)	1.50; [0.74, 3.05]	0.27
Infection Morbidly Obese Vs. Non-obese	5	158 473	3673	52	OR (M – H, Fixed, 95% CI)	5.04; [4.70, 5.39]	< 0.00001
Venous Thromboembolism Obese Vs. Non-obese	5	188 733	2107	72	OR (M – H, Fixed, 95% CI)	3.92; [3.59, 4.28]	< 0.00001
Venous Thromboembolism ^{###} Obese Vs. Non-obese (removal of heavily weighted study)	4	44 494	179	55	OR (M – H, Fixed, 95% CI)	2.40; [1.72, 3.36]	< 0.00001
Venous Thromboembolism [#] Obese Vs. Non-obese	5	188 733	2107	72	OR (M – H, Random , 95% CI)	2.64; [1.66, 4.22]	< 0.00001

Venous Thromboembolism** Morbidly Obese Vs. Non-obese	3	156944	1494	55	OR (M – H, Fixed, 95% CI)	5.46; [4.91, 6.07]	< 0.00001
Venous Thromboembolism** Morbidly Obese Vs. Non-obese ^{###} (removal of heavily weighted study)	2	36 669	118	57	OR (M – H, Fixed, 95% CI)	3.35; [1.97, 5.71]	< 0.00001
Blood Transfusion (ALL) Obese Vs. Non-obese	4	11 937	296	95	OR (M – H, Fixed, 95% CI)	1.47 [1.17, 1.85]	0.0008
Blood Transfusion (ALL) [#] Obese Vs. Non-obese	4	11 937	296	95	OR (M – H, Random , 95% CI)	2.06 [0.48, 8.82]	0.33
Blood Transfusion (ALL) ^{##} Obese Vs. Non-obese (TSA/RTSA Only)	3	4357	164	29	OR (M – H, Fixed, 95% CI)	0.71 [0.52, 0.97]	0.03
Blood Transfusion (ALL) ^{##} Obese Vs. Non-obese (TSA/RTSA Only)	3	4357	164	29	OR (M – H, Random , 95% CI)	1.02 [0.35, 3.01]	0.97
Blood Transfusion Obese Class 2 Vs. Normal	3	1768	71	59	OR (M – H, Fixed, 95% CI)	0.46; [0.28, 0.74]	0.002
Blood Transfusion Obese Class 2 Vs. Normal	3	1768	71	59	OR (M – H, Random , 95% CI)	1.04; [0.18, 5.94]	0.97

Urinary Tract Infection (ALL) Obese Vs. Non-obese	2	4351	43	0	OR (M – H, Fixed, 95% CI)	0.88; [0.48, 1.61]	0.68
Mortality (ALL) Obese Vs. Non-obese	5	37 004	45	0	OR (M – H, Fixed, 95% CI)	1.79 [0.79, 4.03]	0.16
Operative Duration Obese Class 2 Vs. Normal	2	1732	-	4	MD (I – V, Fixed, 95% CI)	12.48 [8.40, 16.55]	< 0.00001
Operative Duration Obese Vs. Normal	3	1955	-	0	MD (I – V, Fixed, 95% CI)	10.00 [6.31, 13.69]	< 0.00001
Operative Duration Obese Vs. Overweight	3	2697	-	0	MD (I – V, Fixed, 95% CI)	4.78 [1.50, 8.07]	0.004
LoS Obese Vs. Normal	2	91	-	14	MD (I – V, Fixed, 95% CI)	0.15 [-0.28, 0.58]	0.48
LoS Morbidly Obese Vs. Non-obese	2	30 203	-	0	MD (I – V, Fixed, 95% CI)	0.28 [0.14, 0.43]	0.0001
LoS Obese Vs. Overweight	2	103	-	45	MD (I – V, Fixed, 95% CI)	0.05 [-0.58, 0.68]	0.88

OR = Odds Ratio; **MD** = Mean Difference; **H – M** = Mantel – Haenszel; **I – V** = Inverse Variance; **CI** = Confidence Interval; **Vs.** = Versus; **Random** = Random Effects Model; **LoS** = Length of Stay; **VTE** = Venous Thromboembolism.

(**ALL**) = All studies that reported this outcome were combined in the meta-analysis comparing BMI < 30.0 versus ≥ 30.0, despite variations in individual study BMI groupings.

Body Mass Index (kg/m²) Groups:

Normal: < 25.0, Overweight: 25.0 – 29.9, Obese: 30.0 – 39.9 (or Obese Class 2: 35.0 – 39.9), Morbidly Obese: ≥ 40.0; Non-obese: < 30.0

*Morris et al. (31) BMI group for *Obese* = BMI > 30.0 kg/m²

****Griffin et al. (27) BMI group for *Morbidly Obese* = BMI > 40.0 kg/m²**

Sensitivity analysis – Random Effects Model when there was substantial or statistically significant heterogeneity:

- Blood Transfusion: Obese Vs. Non-obese (ALL); Obese Class 2 Vs. Normal.
- VTE - Obese Vs. Non-obese

Sensitivity analysis – Excluding TEA site studies

- Blood Transfusion - Obese Vs. Non-obese (ALL) (Random and Fixed effects Models)

Sensitivity analysis – Removal of heavily weighted study

- VTE – Obese Vs. Non-obese
- VTE - Morbidly Obese Vs. Non-obese