CURRENT CONCEPTS REVIEW

The Influence of Obesity on Unicompartmental Knee Arthroplasty Outcomes: A Systematic Review And Meta-Analysis

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Received: 06 March 2021 *Accepted: 28 July 2021*

Abstract

Obesity is associated with a greater prevalence of symptomatic knee osteoarthritis. Obese patients are thought to have worse outcomes following unicompartmental knee arthroplasty (UKA).The aim is to compare clinical and functional outcomes of UKA in obese to non-obese patients.

A systematic review on six databases (PubMed, MEDLINE, Embase, Web of Science, Scopus, and CENTRAL) from inception through July 2020 was performed. We extracted data to determine revision risk (all-cause, septic, and aseptic), complication risk, and infection risk, functional outcome scores (Knee Society Score [KSS], Oxford Knee Score [OKS], and range of movement [ROM]) in patients with obesity (BMI >30kg/m2) to non-obese patients (BMI <30kg/m2). Meta-analysis was performed using a random effects model. The MINORS criteria was used for quality assessment.

Twelve of 715 studies were eligible. Compared with non-obese patients, obese patients had a higher risk ratio for all-cause revision (RR 1.49; 95% CI 1.04 to 2.13; p = 0.03); aseptic revision (RR 1.36; 95% CI 1.01 to 1.81; p=0.04) and complications (RR 2.12; 95% CI 1.17 to 3.85; p=0.01). No significant differences were found in risk of septic revision and overall infection. Obese patients also had lower KSS scores (MD -3.21; 95% CI -5.52 to -0.89; p<0.01), OKS scores (MD -2.21; 95% CI -3.94 to -0.48; p=0.01), and ROM (MD -7.17; 95% CI -12.31 to -2.03; p<0.01). The average MINORS score was 14.2, indicating a moderate quality of evidence.

In conclusion, the risk of revision, aseptic revision, and complications are higher in obese patients. The clinical significance of a lower functional score in obese may not be appreciable. Despite the greater risks, there is no conclusive evidence that obesity should be a contraindication to UKA. Further studies are required to corroborate the current conclusions with higher-quality study designs.

Level of evidence: III

Keywords: Unicompartmental knee arthroplasty, Partial knee, Obesity, Body mass index, Outcomes, meta-analysis

Introduction

Obesity is a global epidemic, with worldwide prevalence of obesity tripling between 1975 and 2016(1). Coinciding with the rising incidence of obesity, there is an uptrend in obese patients requiring joint replacement at a younger age, considering that obesity is a well-known risk factor for the development of knee osteoarthritis (OA)(2–4). For symptomatic unicompartmental knee OA, surgical options for treatment include unicompartmental knee arthroplasty (UKA) and total knee arthroplasty (TKA).

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Whilst TKA has been the gold standard due to its predictability, longevity, and effectiveness (5–8), UKA has risen in popularity as it offers more natural knee kinematics, functional outcomes, less pain, fewer complications and a faster recovery(9–15).

In 1989, Kozinn and Scott first proposed the ideal indications for UKA, including a weight of less than 82kg(16). These criteria were based on the authors' experience and their recommendations produced superior and more consistent results. This led to the wider acceptance and utilization of UKA(17). However, with the improvement of implant designs and surgical techniques, many authors began advocating for the expansion of UKA indications. Recent studies have challenged the view that weight restriction is not justified - even in the heavier groups of patients, obese patients did not have more complications nor inferior clinical and functional outcomes(18–21). Nevertheless, some authors have cautioned that further studies are still required before expanding UKA indications to heavier patients. For example, Nettrour found that morbidly obese patients had >5 times higher rate of early major component revision surgery compared to normal weight and obese patients(22). Bonutti similarly found that patients with BMI ≥35kg/m^2 had a greater risk of early failure compared to those with BMI <35kg/m^2(23).

The aim of this systematic review is to assess whether obesity influences outcomes in patients undergoing UKA. To the authors' knowledge, there is only one published systematic review and meta-analysis evaluating the effects of obesity on revision rate in UKA at present. This study found no difference in revision rate between obese and non-obese patients(24). However, this study did not evaluate clinical and functional outcomes. Therefore, this paper aims to compare the clinical and functional outcomes following UKA in obese patients (defined as BMI >30kg/m^2) as compared to a non-obese population (BMI <30kg/m^2).

Materials and Methods

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement and Cochrane Handbook for Systematic Reviews of Interventions(25,26).

Selection criteria

The inclusion criteria were: Population: adult patients ≥ 18 years old; obese (BMI >30kg/m2)

Intervention: UKA

Comparison: non-obese (BMI <30kg/m2)

Outcomes: Clinical outcomes: overall complications, all infections, revisions (all-cause, septic, and aseptic), aseptic loosening, bearing dislocations, venous thromboembolism (VTE), peri-prosthetic fractures, post-operative stiffness, persistent pain, readmissions, re-operations, mortality, overall implant survivorship, post-operative pain scores reported using the Visual Analogue Scale (VAS)

Functional outcomes: Knee Society Score (KSS), Oxford Knee Scores (OKS), and range of movement (ROM).

Study design: randomized controlled trials, quasi-randomized trials, and cohort studies

The exclusion criteria was if studies were i) not in English; ii) did not directly compare obese and non-obese UKA outcomes of interest; iii) did not use clearly defined World Health Organization groupings.

Search strategy

The search was conducted on 6 databases, using PubMed, MEDLINE via Ovid, Embase, Web of Science, Scopus, and the Cochrane Central Register of Controlled Trials (CENTRAL) from database inception through July 16 2020. The keywords (and related synonyms) used were "unicompartmental knee arthroplasty" and ("obese" OR "body mass index"). The exact details of the search strategy can be found in Appendix 1. There were no limits applied to the search.

Two independent reviewers (HN and WJ) independently performed the search and uploaded their results onto the Rayyan software tool. Duplicates were removed and the titles/abstracts of the retrieved references were screened against the inclusion criteria. All potentially relevant articles were then subjected to full-text search. The two authors independently reviewed these full-text articles using the same inclusion criteria. Finally, the references of the relevant articles were reviewed manually to identify any additional study that would be eligible, but were not picked up by the electronic search. Any discrepancies at any stage were resolved by the senior author.

Data extraction

Data was extracted from eligible studies and recorded in a standardized data extraction form that was pre-defined by our study protocol. Data was then verified by a third reviewer (DR). The data extracted were grouped into study characteristics (author, publication year, study design, level of evidence, sample size, demographics [age, gender, BMI], and follow-up period; surgical characteristics such as type of operation, type of implants; and outcomes of interest.

Level of evidence and quality assessment

The level of evidence was defined using the Oxford Centre for Evidence-Based Medicine (OCEBM) criteria(27). Risk of bias was evaluated using the Methodological Index for Non-Randomised Studies (MINORS) criteria(28). Any disagreement was resolved by group discussion.

Statistical analysis

The relative risk (RR) were used as a summary statistic for dichotomous variables. The mean difference (MD) and 95% CI were calculated for continuous variables. We calculated the pooled estimates and 95% CI for both the RR and MD. The results were reported using forest plots, including individual and pooled estimates along with 95% CI.

If a continuous variable was reported with a range, the standard deviation (SD) was calculated using the method described by Walter and Yao(29). If studies reported median and range, the means and SD were calculated using the method described by Hozo(30). For functional outcome scores, we used the analysis of final values at the latest follow-up for calculation, as a large proportion of the included studies did not report either the pre-operative functional outcome scores for calculation of the change scores, or the change scores.

Heterogeneity was calculated using the I2 statistic(31). Meta-analysis was performed using a random-effects model to take into account the methodological variation and clinical differences between studies. A chi-square p-value <0.1 was suggestive of statistical heterogeneity, while a p-value of <0.05 was considered as statistically significant. Evaluation for publication bias was not carried out as none of the outcomes of interest had 10 included studies.

Data analysis was performed with RevMan (Review Manager) software (RevMan 5.4, Cochrane Collaboration).

Results

Study selection

The search identified 715 studies. Twelve studies met our inclusion and exclusion criteria. The PRISMA flow diagram is shown in [Figure 1].

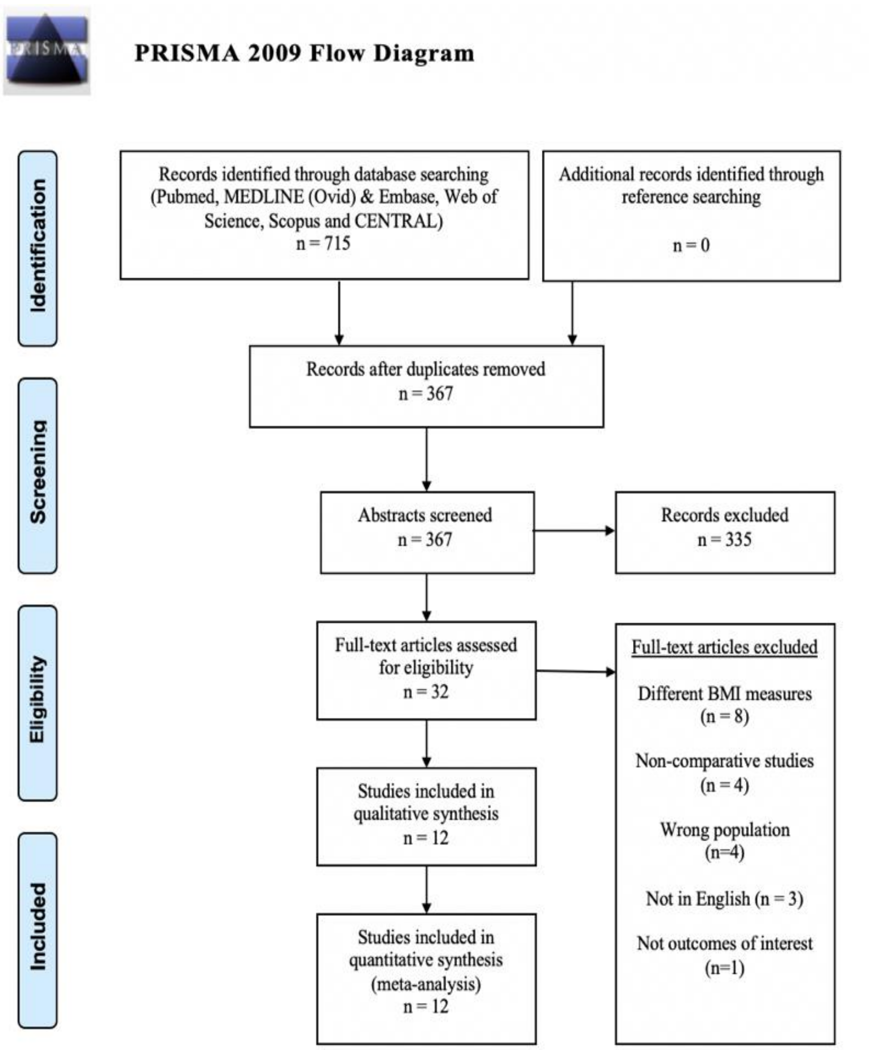

Figure1. Prisma flow diagram

We identified eight retrospective studies and four prospective studies. The characteristics of the studies are detailed in [Table 1]. Five studies included fixed-bearing UKA implants (32–36), while three studies used a mobile-bearing UKA implant(37–39). The type of UKA implants used were not available in four studies(40–43).

Demographics

These studies included 29484 patients. The mean age was 64 years. The baseline characteristics are seen in [Table 1] and [Appendix 2]. The reported follow-up periods ranged from a minimum of 30 days to 12.2 years. Eleven studies had follow-up data of >1 year, where the remaining study reported on early 30-day complications(40).

Level of evidence

As seen in [Table 1], four studies were level 2b prospective cohort studies (33,37,38,42), while the remaining 8 studies were level 3b retrospective studies(32,34–36,39–41,43). None of the studies were randomized clinical trials.

Quality assessment

The mean MINORS score was 14.2 (range 11 – 19). This is seen in [Table 1], and further described in [Appendix 3]. All of the studies had clearly stated aims, endpoints appropriate to the aim of the study, an adequate control group, and adequate statistical analyses. Most of the studies did not perform prospective collection of the data (in view that most of the studies were retrospective studies), had biased assessment of the study end-point, and did not report on proportion of patients lost to follow-up. Overall, this indicates a moderate average quality of evidence.

Outcomes of interest - Clinical outcomes

Overall complication rate

Five articles reported overall complications(33,34,39–41). This included all complications reported in the articles (major and minor complications). Obese patients had a statistically significant higher risk of complications (RR 2.12, 95% CI 1.17 to 3.85, p=0.01) [Figure 2].

Overall infection rate

Eight studies reported infection rates (33–35,37–41), including three studies which did not differentiate between deep or superficial infection rates(37,38,41). Obese and non-obese patients had statistically similar risks of infection (RR 1.23, 95% CI 0.72 to 2.08, p=0.50) [Figure 3].

Table 1. Study characteristics, level of evidence, risk of bias and demographic information of included studies

Author (year)	LoE	Study design	Type of implants (Fixed bearing / mobile bearing)	Total patients (knees) Average age (SD) (years)	Average age (SD) (years)	Follow-up length (SD)	Outcomes of interest (Clinical)	Outcomes of interest (Functional)	MINORS score
Kandil (2014) 41	3b	Retrospective (registry data)	NA	15770	NA	90 days – 7 years	Complications Infection Revision Stiffness VTE	-	12
Lash (2013) 42	2b	Cohort	NA	326	67.2 (13.6)	1 year	-	OKS	17
Molloy (2018) 37	2b	Cohort	Oxford partial knee Mobile bearing	941 (956)	66.6 (9.9)	10.2 (3) years	Aseptic loosening Bearing dislocation Persistent pain Revision Infection Survival	OKS	16
Murray (2013) 38	2b	Cohort	Oxford partial knee Mobile bearing	(2438)	64 (15.9)	4.6 (1-12) years	Aseptic loosening Bearing dislocation Infection Periprosthetic fracture Persistent pain Revision Survival	American KSS (Functional and Objective) OKS	19
Naal (2009) 43	3b	Retrospective	DePuy Preservation NA	77 (83)	66 (9.3)	2 years	VAS for anterior knee pain	KSS (Function and Knee score) ROM	15

Plate (2017)[36]	3b	Retrospective (registry data)	Robotic MAKO UKA Fixed bearing	672 (746)	64 (11)	34.6 (7.8) months	Revision	-	15
Polat (2019)[39]	3b	Retrospective	Oxford partial knee Mobile bearing	104	60.2 (7.4)	46 (14.6) months	Complications Infection Revision VAS for pain	KSS (Function and Knee score) OKS ROM	13
Sundaram (2019)[40]	3b	Retrospective (registry data)	NA	8029	64 (10.5)	At least 30 days	30-day readmission Complications Infection Length of operation Mortality Re-operations VTE	-	15
Venkatesh (2019)[35]	3b	Retrospective	Zimmer Miller-Galante Fixed bearing	148 (175)	61.7 (10.4)	63.6 (26.3) months	Aseptic loosening Infection Revision Persistent pain	KSS (Function and Knee score)	11
Woo (2017)[34]	3b	Retrospective	Fixed bearing	673 (673)	62 (12.5)	5.4 (2.4 – 8.5) years	Aseptic loosening Complications Infection Periprosthetic fracture Persistent pain Revision Stiffness VTE	KSS (Function and Knee score) OKS	12
Xu (2019)[33]	2b	Cohort	Zimmer Miller Galante & DePuy Preservation Fixed bearing	184 (184)	61.1 (6.3)	At least 10 years	Aseptic loosening Complications Infection Periprosthetic fracture Re-operation Revision Survival	KSS (Function and Knee score) OKS ROM	12
Zengerink (2015)[32]	3b	Retrospective	Fixed bearing	122 (137)*	60.5 (7.3)	2 – 12.2 years	Persistent pain Re-operations Infection Survival VAS for pain		13

*pre-operative BMI in 10 patients were missing
KSS: Knee Society Score; LoE: Level of Evidence; NA: Not Available OKS: Oxford Knee Score; ROM: Range of Movement; SD: Standard deviation; VAS: Visual Analogue Scale; VTE: Venous thromboembolism

Table 2. Summary of the meta-analysis results

Outcome	No. of patients	No. of events	Heterogeneity, I^2 (%)	Risk ratio (95% CI)
Persistent pain	4369	38	11	1.59 (0.75 to 3.36)
Aseptic loosening	4426	24	1	1.69 (0.72 to 3.96)
Peri-prosthetic fracture	3295	5	0	2.95 (0.56 to 15.63)
Bearing dislocation	3394	15	0	1.60 (0.58 to 4.42)
Post-operative stiffness	16443	72	0	0.85 (0.66 to 1.09)
Re-operation	8213	93	85	2.05 (0.51 to 8.30)
VTE	24472	193	9	*2.46 (1.73 to 3.50)*
Readmission rate	8029	189	NA	0.85 (0.64 to 1.13)
Mortality	8029	4	NA	0.26 (0.03 to 2.48)

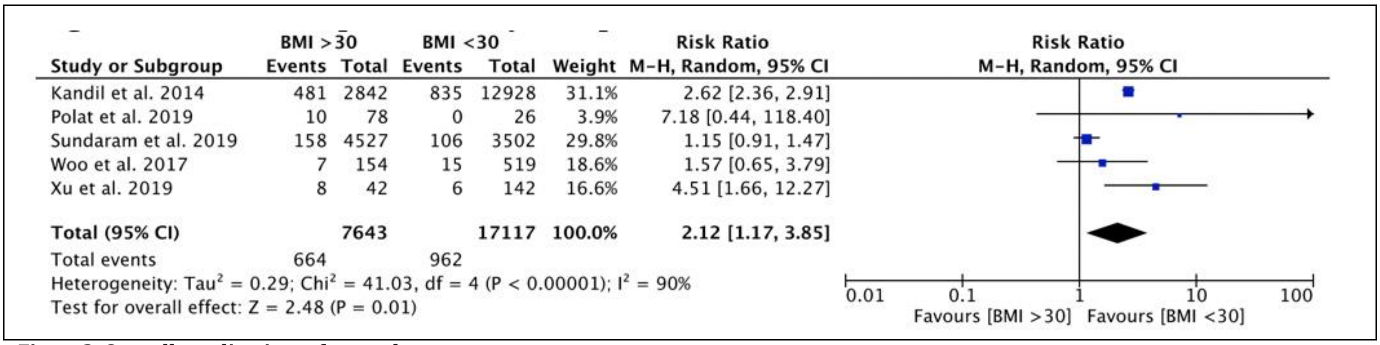

Figure2. Overall comlications- forest plot

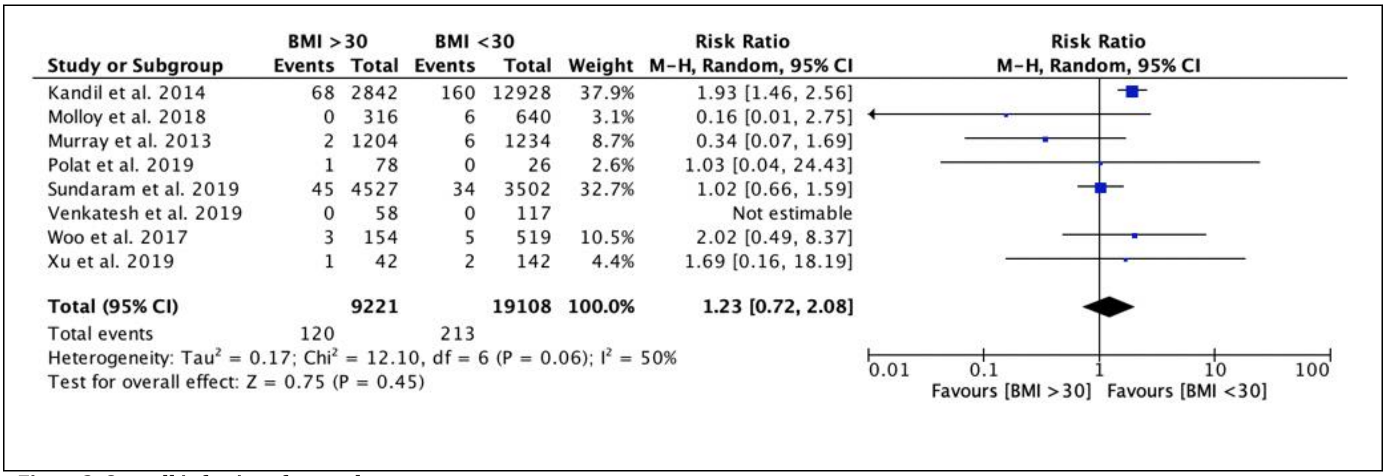

Figure3. Overall infection- forest plot

Revision outcomes

Nine studies reported on all-cause revision rates(32–39,41). Obese patients had a statistically higher risk of revisions (RR 1.49, 95% CI 1.04 to 2.13, p = 0.03) [Figure 4]. Kandil did not report on the different causes of revision, hence this study was excluded from further analysis(41). While obese patients had statistically similar risk of septic revisions (RR 0.97, 95% CI 0.25 to 3.80, p=0.97) [Figure 5], they had a higher risk of aseptic revisions (RR 1.36, 95% CI 1.01 to 1.82, p=0.04) [Figure 6].

Other complications

Five studies reported on rates of persistent pain (32,34,35,37,38) and aseptic loosening (33–35,37,38), three studies reported rates of VTE (34,40,41) and peri-prosthetic fracture (33,34,38), two studies reported rates of bearing dislocation (37,38), post-operative stiffness (34,41) and re-operation (33,40), while only one study reported on rates of readmission and mortality (40). Four studies reported on overall implant survivorship, summarized in [Appendix 4] (32,33,37,38). A combined Kaplan-Meier survival analysis was not performed due to the inability to extract raw data.

There was low heterogeneity for the other complications that occurred, which allowed pooling of the results. There were no significant differences between obese and non-obese patients for risk of persistent pain, aseptic loosening, peri-prosthetic fractures, bearing dislocation, post-operative stiffness, re-operation, 30-day readmission, mortality and pain scores [Table 2; Appendix 5, Figures 1 – 7]. The lack of difference may be the result of the small number of events in these studies [Table 2].

Obese patients had a significantly higher risk of venous thromboembolism, including deep venous thromboembolism and/or pulmonary embolism (RR 2.46, 95% CI 1.73 to 3.50, p<0.01) [Table 2; Appendix 5, Figure 8].

Functional outcomes

For functional outcomes, the most common outcome measure used was the KSS and OKS scores. Range of movement was reported in three studies(33,39,43). Knee pain was reported using the VAS in three studies(32,39,43).

Six studies reported KSS scores (33–35,38,39,43) and OKS scores(33,34,37–39,42). No significant difference was found for KSS clinical scores (MD -1.96, 95% CI -4.74 to 0.82, p=0.17) [Figure 7]. However, obese patients had statistically significant lower KSS function scores (MD -4.45, 95% CI -7.93 to -0.97, p <0.01) [Figure 7], overall KSS scores (MD -3.21, 95% CI -5.52 to -0.89, p<0.01), OKS scores (MD -2.21, 95% CI -3.94 to -0.48, p=0.01) [Figure 8], and reduced ROM (MD -7.17, 95% CI -12.3 to -2.03, p<0.01) [Figure 9].

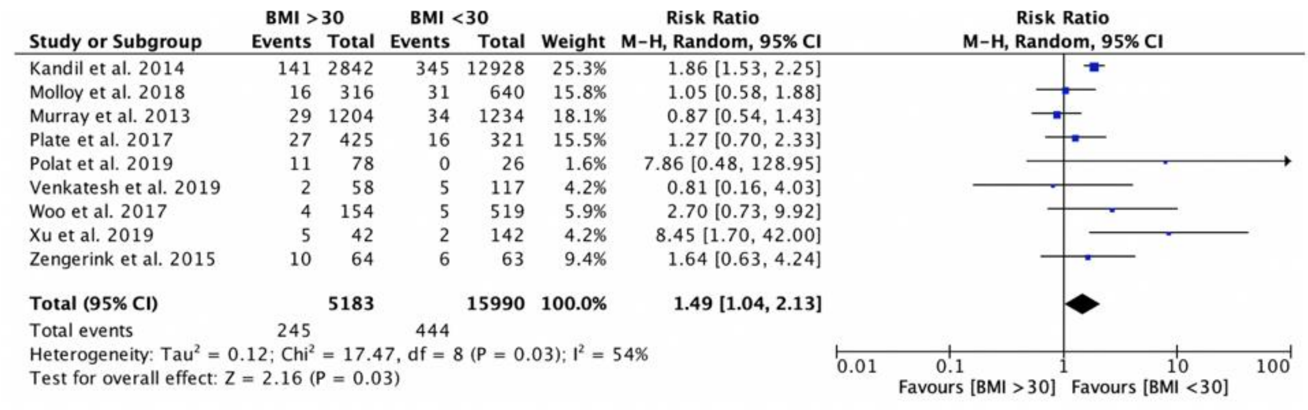

Figure4. Overall all-cause revision-forest plot

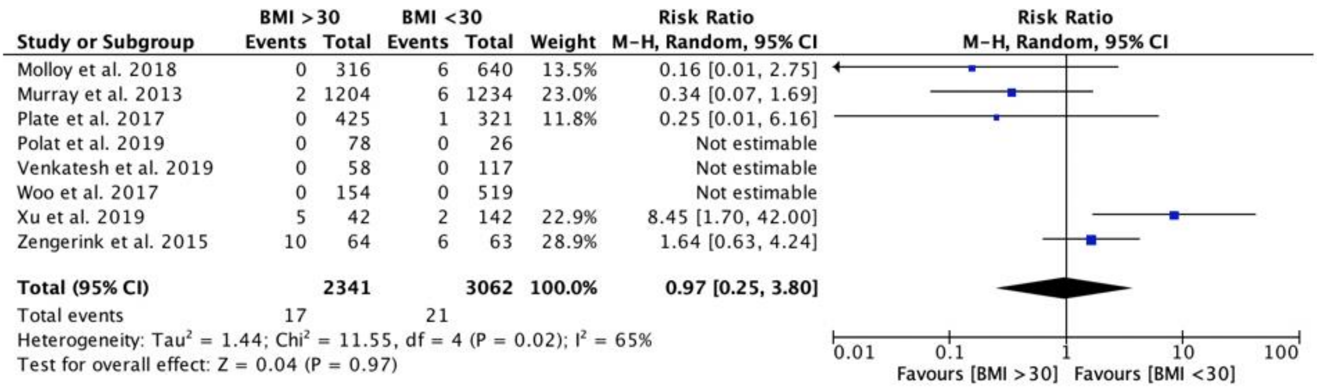

Figure5. Septic revisin- forest plot

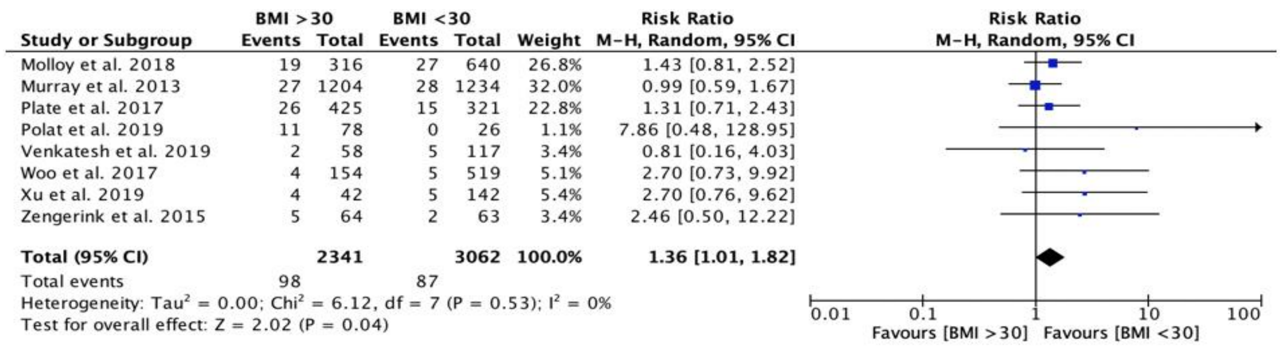

Figure6. Aseptic revision- forest plot

Discussion

The influence of obesity on outcomes of UKA is still controversial. While there have been many studies demonstrating that BMI does not influence the results of a UKA (34,35,38,44–46), there similarly has been numerous studies that have demonstrated a positive correlation between BMI and failure rate after UKA(22,23,47). Thus, the aim of this review was to examine the influence of obesity on clinical and functional outcomes in patients undergoing UKA. The results of our meta-analysis suggests that the obese population is at a higher risk for overall complications, overall revision, aseptic revision and VTE.

We found that obese patients had a statistically significant higher risk of overall complications. This could be due to more comorbidities and a lengthier hospitalization seen in obese patients, both of which are associated with higher complication rates(41,48–50). Not only that, obesity is an established independent risk factor for complications in all joint replacements(48,51).

Specifically, we also found that obese patients had a higher risk of VTE (RR 2.46, 95% CI 1.73 to 3.50, p<0.01). Reasons to explain this are that obesity is itself a risk factor for VTE, and obese patients are typically slower to mobilize(52). While the use of VTE prophylaxis was not examined nor reported in the included studies, nevertheless, the increased risk of VTE in obese patients underscores the importance of increased vigilance that surgeons should have on the development of VTE in obese patients.

Of note, we did not find that obese patients had a higher risk of overall infection (RR 1.23, 95% CI 0.72 – 2.08, p=0.50), even though higher BMIs and multiple comorbidities have been associated with higher rates of infection (both superficial and deep).

In terms of overall revision risk, we found that obese patients were 1.5 times more likely to undergo revision surgery (RR 1.49, 95% CI 1.04 to 2.13, p = 0.03). An explanation for this may the higher proportion of younger and predominantly female obese patients seen in our review. The average age was 61.8 years in the obese as compared to 65.9 years in the non-obese, and 57% females in the obese versus 52.7% in the non-obese. Van der List found a higher risk of revision was associated with younger (OR 2.09, 95% CI 1.70 to 2.57 in registries; OR 1.52, 95% CI 1.06 to 2.19 in studies) and female patients (OR 1.13, 95% CI 1.06 to 1.21)(53). Additionally, younger patients tend to be more active. A higher activity level increases the risk of aseptic loosening and polyethylene wear(54–57).

Another reason for an increased risk for revision surgery in the obese could be related to component malposition errors which increase revision rates(39,56,58,59). The visual field may be restricted, especially if minimally invasive surgery was performed. This gives rise to technical difficulties which may result in component malposition errors(56).

Also, obese patients were more likely to undergo aseptic revision (RR 1.36, 95% CI 1.01 to 1.82, p=0.04). Musbahi, in their meta-analysis of revision rate in UKA in obese patients, found that unexplained pain increased the revision rate significantly in the obese patients (OR 3.66, 95% CI 1.09 to 12.30). Similarly, a meta-analysis on revision risk of UKA converted to TKA found that the most common causes of revision were aseptic loosening (38%), instability (26%) and unexplained pain (13%)(60). Although we found no difference in the risk of unexplained pain and aseptic loosening in obese and non-obese patients, the lack of difference may be the result of the small number of events in these studies [Table 2].

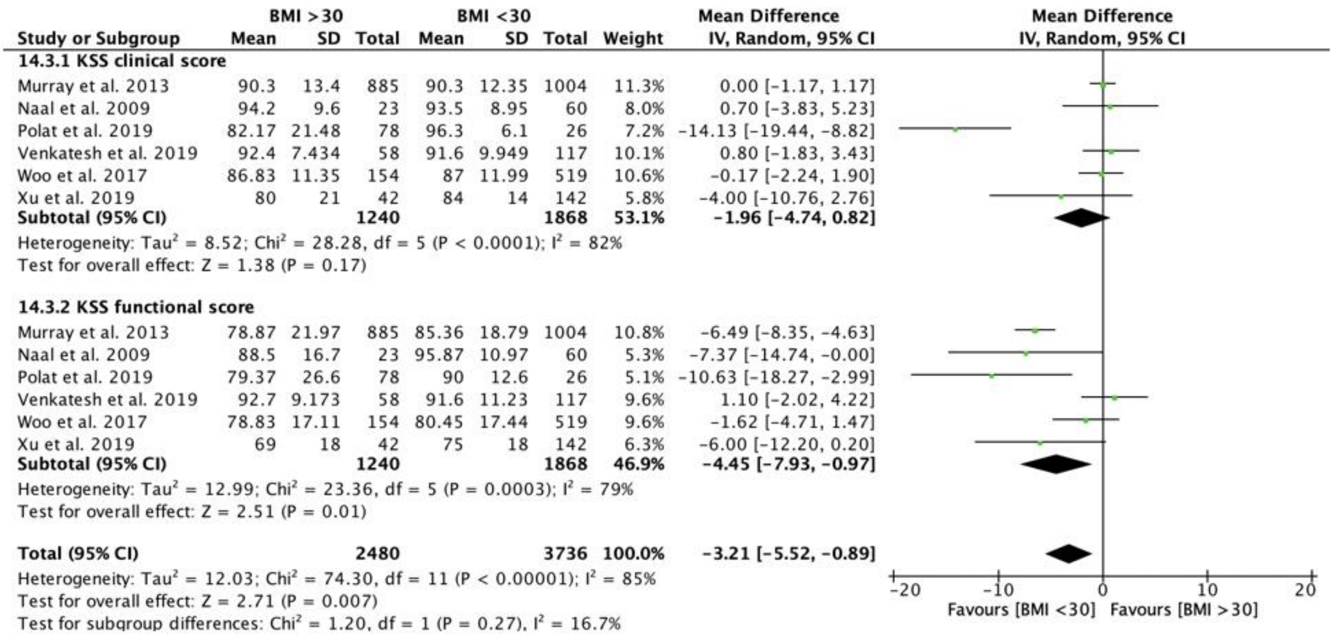

Figure7. KSS scores- forest plot

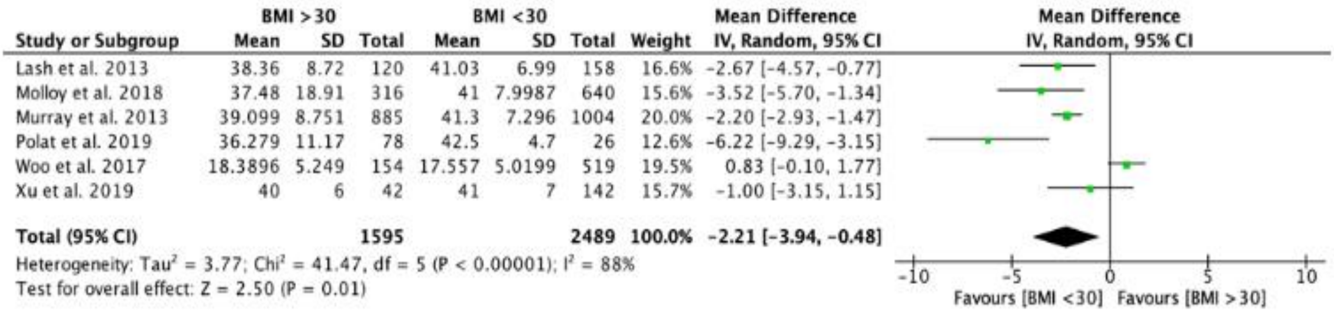

Figure8. OKS - forest plot

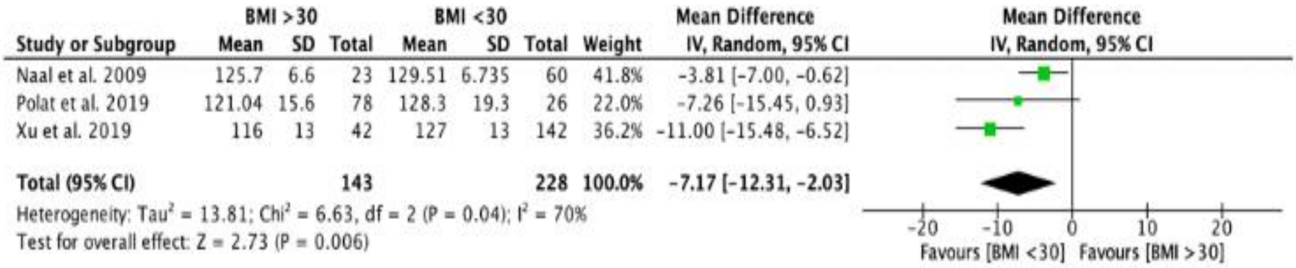

Figure9. Range of movement- forest plot

Also, obese patients were more likely to undergo aseptic revision (RR 1.36, 95% CI 1.01 to 1.82, p=0.04). Musbahi, in their meta-analysis of revision rate in UKA in obese patients, found that unexplained pain increased the revision rate significantly in the obese patients (OR 3.66, 95% CI 1.09 to 12.30). Similarly, a meta-analysis on revision risk of UKA converted to TKA found that the most common causes of revision were aseptic loosening (38%), instability (26%) and unexplained pain (13%)(60). Although we found no difference in the risk of unexplained pain and aseptic loosening in obese and non-obese patients, the lack of difference may be the result of the small number of events in these studies [Table 2].

Obese patients also had statistically significant lower KSS scores, KSS function scores, OKS scores, and ROM at the final follow-up. Arguably, the clinical significance of this difference in functional scores is questionable, given that there was a small difference for KSS function scores (MD -4.45, 95% CI -7.93 to -0.97, p <0.01) on a scale of 0-100 and OKS scores (MD -2.21, 95% CI -3.94 to -0.48, p=0.01) on a scale of 0-48.

Given the significant advantages of UKA over TKA in patients who have unicompartmental knee OA, the increased risks of complications and revision may be acceptable(61). For example, we found that the absolute risk of complication, revision and aseptic revision in obese patients were 8.7%, 4.7% and 4.2% respectively. Although substantial, these values are potentially acceptable depending on the clinical circumstance.

Conversely, some surgeons may feel that these risks are unacceptable, since the higher incidence of failures were associated with patients who did not fall into the strict indications(62). However, it is important to note that obese patients undergoing TKA also had higher rates of revision (OR 1.30, 95% CI 1.02 – 1.67), overall infection (OR 1.90, 95% CI 1.46 – 2.47), and deep infection (OR 2.38, 95% CI 1.28 – 4.55).(63)

In consideration of the above points, ultimately, we believe that the determination of candidacy for UKA would be a patient-specific decision. The decision requires a discussion with the patient in a shared decision-making model with a risk-benefit analysis. Careful patient selection can lead to a higher success rate of UKA.

Our study has several strengths. We have included all studies, including database and registry data, reporting on our outcomes of interest. We only included comparative studies in this systematic review, representing the best evidence to compare outcomes between the obese and non-obese. Also, we utilized a meta-analysis to quantitatively summarize the results of available literature to provide more precise estimates of the effect.

The main limitation for our meta-analysis was based on the quality of the included studies. Most of the included studies within this review had a retrospective study design with its inherent limitations. Secondly, although all studies were included in the quantitative analysis, the studies did not report on all the outcomes of interest that were pooled in our analysis. As a result, some of the outcomes of interest had few included studies, which may have affected the pooled results. Confounding factors that could have influenced outcomes of interest were also not reported frequently nor consistently across the studies.

There was a large variation in number of patients and the length of follow-up in the included studies, contributing to clinical heterogeneity. Also, analysis of the difference in change in functional outcomes, arguably a better representation to compare the effectiveness of UKA on functional outcomes in both groups, could not be examined due to inconsistent reporting and missing data of pre-operative functional outcomes. Again, the mean time to the revision surgery was rarely reported, which made it difficult to determine when revisions were performed. Although we did not perform a subgroup analysis for outcomes in the higher BMI groups due to a small number of studies with sub-categories of BMI, it is important to note that there is no definite BMI cut-off point where the impact of obesity on outcomes following UKA is binary.

The results of our study must be corroborated with further high quality prospective study designs or randomized controlled trial designs with analysis adjusting for confounding variables, with clearly reported outcomes and follow-up intervals to determine the early, mid and long-term outcomes of obesity on UKA.

Conclusions

In conclusion, our meta-analysis demonstrates that obese patients have a greater risk of complications, revision, aseptic revision and VTE. The risk of overall infection is similar in obese and non-obese patients, with clinically similar post-operative functional scores. Obese patients must be counselled regarding the increased risks of complications and revision associated with obesity, and encouraged to lose weight pre-operatively. However, obese patients should not be precluded from UKA based on BMI alone as UKA is likely to offer patients a significant improvement in functional outcomes. Future studies are required to corroborate the current conclusions with higher-quality study designs.

Funding: No funding was required or received for this study.
Conflicts of interest/Competing interests: The authors have no conflicts of interests to declare.
Availability of data and material: not applicable
Code availability: not applicable
Ethics approval: not applicable
Consent to participate: not applicable
Consent for publication: not applicable

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Appendix 1. Search Strategy

PubMed

("unicompartmental knee replacement" or "unicompartmental knee replacements" or "unicompartmental knee arthroplasty" or "unicompartmental knee arthroplasties" or "unicondylar knee arthroplasty" or "unicondylar knee replacement" or "unicondylar knee replacements" or "unicondylar knee arthroplasties" or "partial knee replacement" or "partial knee replacements" or "partial knee arthroplasty" or "partial knee arthroplasties" or "UKA" or "UKR") [All fields] AND ("BMI" or "body mass index" or "obese" or "obesity" or "overweight" or "morbidly obese" or "severely obese") [All fields]

Appendix 2. Patient demographics of included studies

Author (year)	**Non-obese (BMI < 30kg/m²)**				**Obese (BMI > 30kg/m²)**			
	BMI (kg/m²)	**No. of patients (knees)**	**Age (SD) (years)**	**Males (%)**	**BMI (kg/m²)**	**No. of patients (knees)**	**Age (SD) (years)**	**Males (%)**

Kandil (2014) (41)	<30	12928	<65: 6532 65 – 80: 5162 >80: 1234	47.6	30 – 39	1823	<65: 628 65 – 80: 1049 >80: 146	41.5
					>40	1019	<65: 582 65 – 80: 410 >80: 27	35.7
Lash (2013) (42)	<25	41	NA	NA	31 – 35	99	NA	NA
	25 - 30	145	NA	NA	>35	41	NA	NA
Molloy (2018) (37)	<25	202 (207)	70.3 (10)	36	30 - <35	218 (220)	64.9 (9)	55
	25 - <30	427 (433)	66.4 (10)	59	>35	94 (96)	61.7 (8)	44
Murray (2013) (38)	<25	(378)	69 (15.4)	NA	30 - <35	(712)	61 (15.6)	NA
	25 - <30	(856)	65 (16.2)	NA	35 - <40	(286)	61 (15.3)	NA
					40 - <45	(126)	58 (13.4)	NA
					≥45	(80)	59 (10.7)	NA
Naal (2009) (43)	<25	13	NA	NA	≥30	23	NA	NA
	25 – 29.9	47	NA	NA				
Plate (2017) (36)	<18.5	(1)	NA	NA	30 – 34.9	(227)	NA	NA
	18.5 – 24.9	(91)			35 – 39.9	(115)		
	25 – 29.9	(229)			40 – 44.9	(42)		
					>45	(41)		
Polat (2019) (39)	<30	26	61.5 (7.3)	15.4	30 – 34.9	40	60.5 (7.7)	20
					≥35	38	59 (7.1)	15.8
Sundaram (2019) (40)	18.5 – 24.9	952	67 (12)	37.4	30 – 39.9	3787	63 (10)	48.7
	25 – 29.9	2550	66 (10)	54.9	≥40	740	58 (9)	31.1
Venkatesh (2019) (35)	<30	(117)	62.5 (9)	NA	>30	(58)	60.2 (7.6)	NA
Woo (2017) (34)	<25	230	65 (8)	23.0	30 – 34.9	124	61 (8)	25.8
	25 – 29.9	289	62 (8)	28.0	≥35	30	58 (9)	13.3
Xu (2019) (33)	<30	142	62.4 (7.8)	22.5	≥30	42	56.5 (6.4)	11.9
Zengerink (2015) (32)	<30	(63)	60 (8.1)	38	>30	(64)	60.9 (6.6)	36

Appendix 3. Survivorship summary

Author (year)	**All-cause survivorship**						**Overall**
Molloy (37)	**BMI <25** 10 year: 92% (CI: 86 – 96)	**BMI 25 - <30** 10 year: 95% (CI: 92 – 97)	**BMI 30 - <35** 10 year: 94% (CI: 90 – 98)		**BMI >35** 10 year: 93% (CI: 87 – 99)		NA
Murray (38)	**BMI <25** 5 year: 97.6% (CI: 95.8 – 99.3) 10 year: 94.9% (CI: 90.8 – 99.1)	**BMI 25 - <30** 5 year: 96.8% (CI: 95.4 – 98.2) 10 year: 93% (CI: 89 – 97)	**BMI 30 - <35** 5 year: 95.3% (CI 93.1 – 97.5) 10 year: 95.3% (CI 93.1 – 97.5)	**BMI 35 - <40** 5 year: 93.8% (CI: 88.9 – 98.6) 10 year: 93.8% (CI 89 – 98.6)	**BMI 40 - <45** 5 year: 95.2% (CI: 90.7 – 99.8)	**BMI ≥45** 5 year: 100%	NA
Xu (33)	**BMI<30** 10 year: 98.6%		**BMI ≥30** 10 year: 88.1%				NA
Zengerink (32)	**BMI <30** NA		**BMI >30** NA				10-year: 87%

CI: Confidence interval; NA: Not Available

Appendix 4. Risk of Bias assessment using the MINORS criteria

Study	1	2	3	4	5	6	7	8	9	10	11	12	Total
Kandil (41)	2	0	0	2	0	2	0	0	2	1	1	2	12
Lash (42)	2	2	2	2	1	2	1	0	2	1	0	2	17
Molloy (37)	2	2	2	2	0	2	0	0	2	1	1	2	16
Murray (38)	2	2	2	2	0	2	1	2	2	2	0	2	19
Naal (43)	2	2	0	2	0	2	0	0	2	2	1	2	15
Plate (36)	2	1	0	2	0	2	1	0	2	2	1	2	15
Polat (39)	2	1	0	2	0	2	0	0	2	1	1	2	13
Sundaram (40)	2	0	1	2	2	2	0	0	2	1	1	2	15
Venkatesh (35)	2	0	0	2	0	2	0	0	2	1	0	2	11
Woo (34)	2	0	0	2	0	2	0	0	2	1	1	2	12
Xu (33)	2	0	0	2	0	2	0	0	2	1	1	2	12
Zengerink (32)	2	0	0	2	0	2	2	0	2	1	0	2	13

Appendix 5. Other complications

Study or Subgroup	BMI >30 Events	BMI >30 Total	BMI <30 Events	BMI <30 Total	Weight	Risk Ratio M-H, Random, 95% CI
Molloy et al. 2018	4	316	3	640	21.9%	2.70 [0.61, 11.99]
Murray et al. 2013	8	1204	10	1234	46.8%	0.82 [0.32, 2.07]
Venkatesh et al. 2019	2	58	2	117	13.8%	2.02 [0.29, 13.96]
Woo et al. 2017	0	154	1	519	5.3%	1.12 [0.05, 27.31]
Zengerink et al. 2015	7	64	1	63	12.2%	6.89 [0.87, 54.40]
Total (95% CI)		**1796**		**2573**	**100.0%**	**1.59 [0.75, 3.36]**
Total events	21		17			

Heterogeneity: $Tau^2 = 0.09$; $Chi^2 = 4.50$, df = 4 (P = 0.34); $I^2 = 11\%$
Test for overall effect: Z = 1.21 (P = 0.23)

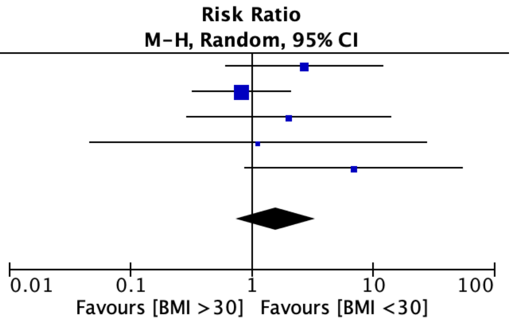

Figure 1. Persistent pain – forest plot

Study or Subgroup	BMI >30 Events	BMI >30 Total	BMI <30 Events	BMI <30 Total	Weight	Risk Ratio M-H, Random, 95% CI
Molloy et al. 2018	0	316	2	640	7.8%	0.40 [0.02, 8.40]
Murray et al. 2013	11	1204	6	1234	69.3%	1.88 [0.70, 5.06]
Venkatesh et al. 2019	0	58	2	117	7.9%	0.40 [0.02, 8.20]
Woo et al. 2017	0	154	1	519	7.1%	1.12 [0.05, 27.31]
Xu et al. 2019	2	42	0	142	7.9%	16.63 [0.81, 339.76]
Total (95% CI)		**1774**		**2652**	**100.0%**	**1.69 [0.72, 3.96]**
Total events	13		11			

Heterogeneity: $Tau^2 = 0.02$; $Chi^2 = 4.04$, df = 4 (P = 0.40); $I^2 = 1\%$
Test for overall effect: Z = 1.21 (P = 0.23)

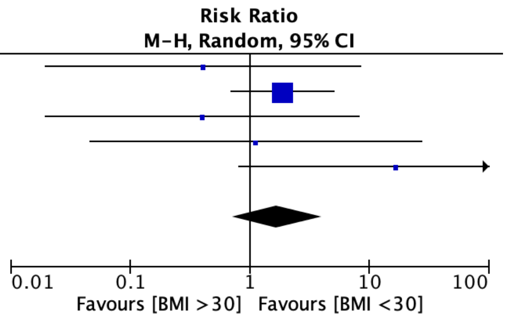

Figure 2. Aseptic loosening – forest plot

Study or Subgroup	BMI >30 Events	BMI >30 Total	BMI <30 Events	BMI <30 Total	Weight	Risk Ratio M-H, Random, 95% CI
Murray et al. 2013	1	1204	1	1234	36.1%	1.02 [0.06, 16.37]
Woo et al. 2017	1	154	0	519	27.2%	10.06 [0.41, 245.82]
Xu et al. 2019	1	42	1	142	36.7%	3.38 [0.22, 52.91]
Total (95% CI)		**1400**		**1895**	**100.0%**	**2.95 [0.56, 15.63]**
Total events	3		2			

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.14$, df = 2 (P = 0.57); $I^2 = 0\%$
Test for overall effect: Z = 1.27 (P = 0.20)

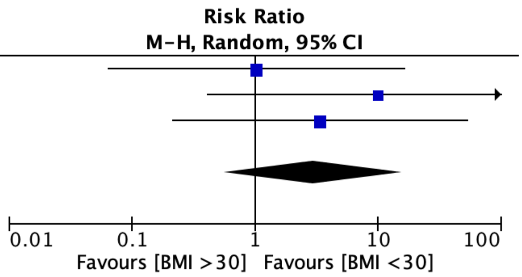

Figure 3. Peri-prosthetic fractures – forest plot

	BMI >30		BMI <30			Risk Ratio
Study or Subgroup	**Events**	**Total**	**Events**	**Total**	**Weight**	**M-H, Random, 95% CI**
Molloy et al. 2018	4	316	3	640	46.3%	2.70 [0.61, 11.99]
Murray et al. 2013	4	1204	4	1234	53.7%	1.02 [0.26, 4.09]
Total (95% CI)		**1520**		**1874**	**100.0%**	**1.60 [0.58, 4.42]**
Total events	8		7			

Heterogeneity: Tau² = 0.00; Chi² = 0.87, df = 1 (P = 0.35); I² = 0%
Test for overall effect: Z = 0.91 (P = 0.36)

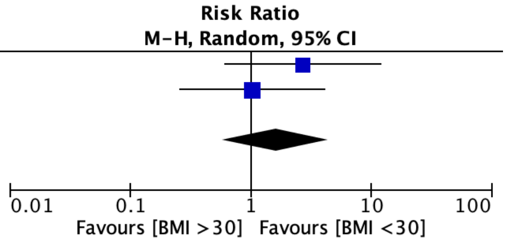

Figure 4. Bearing dislocation – forest plot

	BMI >30		BMI <30			Risk Ratio
Study or Subgroup	**Events**	**Total**	**Events**	**Total**	**Weight**	**M-H, Random, 95% CI**
Kandil et al. 2014	72	2842	385	12928	99.3%	0.85 [0.66, 1.09]
Woo et al. 2017	0	154	3	519	0.7%	0.48 [0.02, 9.23]
Total (95% CI)		**2996**		**13447**	**100.0%**	**0.85 [0.66, 1.09]**
Total events	72		388			

Heterogeneity: Tau² = 0.00; Chi² = 0.14, df = 1 (P = 0.70); I² = 0%
Test for overall effect: Z = 1.31 (P = 0.19)

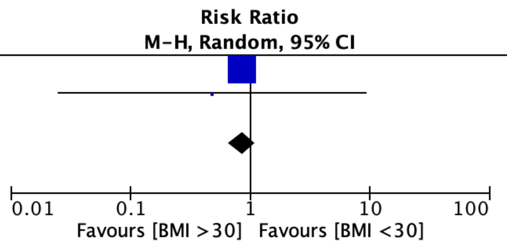

Figure 5. Post-operative stiffness – forest plot

	BMI >30		BMI <30			Risk Ratio
Study or Subgroup	**Events**	**Total**	**Events**	**Total**	**Weight**	**M-H, Random, 95% CI**
Sundaram et al. 2019	46	4527	33	3502	55.1%	1.08 [0.69, 1.68]
Xu et al. 2019	8	42	6	142	44.9%	4.51 [1.66, 12.27]
Total (95% CI)		**4569**		**3644**	**100.0%**	**2.05 [0.51, 8.30]**
Total events	54		39			

Heterogeneity: Tau² = 0.87; Chi² = 6.59, df = 1 (P = 0.01); I² = 85%
Test for overall effect: Z = 1.01 (P = 0.31)

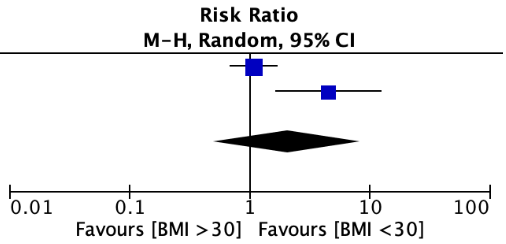

Figure 6. Re-operation rate – forest plot

	BMI >30			BMI <30				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Naal et al. 2009	2.5	3.2	23	1.97	2.294	60	27.3%	0.53 [-0.90, 1.96]
Polat et al. 2019	2.982	3.217	78	1.6	1.9	26	33.9%	1.38 [0.36, 2.40]
Zengerink et al. 2015	0.9	1.6	53	1.3	2.2	57	38.8%	-0.40 [-1.12, 0.32]
Total (95% CI)			**154**			**143**	**100.0%**	**0.46 [-0.73, 1.64]**

Heterogeneity: Tau² = 0.81; Chi² = 8.04, df = 2 (P = 0.02); I² = 75%
Test for overall effect: Z = 0.76 (P = 0.45)

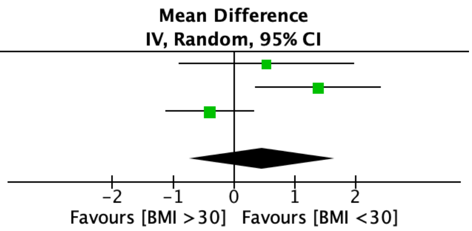

Figure 7. Pain (Visual Analogue Scale) – forest plot

	BMI >30		BMI <30			Risk Ratio
Study or Subgroup	**Events**	**Total**	**Events**	**Total**	**Weight**	**M-H, Random, 95% CI**
Kandil et al. 2014	60	2842	98	12928	77.1%	2.79 [2.02, 3.83]
Sundaram et al. 2019	22	4527	11	3502	21.3%	1.55 [0.75, 3.19]
Woo et al. 2017	1	154	1	519	1.6%	3.37 [0.21, 53.57]
Total (95% CI)		**7523**		**16949**	**100.0%**	**2.46 [1.73, 3.50]**
Total events	83		110			

Heterogeneity: Tau² = 0.02; Chi² = 2.20, df = 2 (P = 0.33); I² = 9%
Test for overall effect: Z = 5.03 (P < 0.00001)

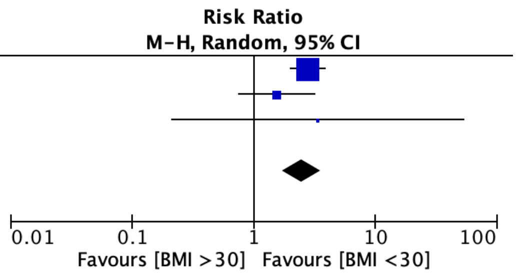

Figure 8 VTE – forest plot