ORIGINAL ARTICLE
Hip Pelvis 34(3): 161-171, 2022
https://doi.org/10.5371/hp.2022.34.3.161

Print ISSN 2287-3260
Online ISSN 2287-3279
Hip & Pelvis

Total Hip Arthroplasty in Morbidly Obese: Does a Strict Body Mass Index Cutoff Yield Meaningful Change?

Niall Cochrane, MD, Sean Ryan, MD, Billy Kim, BA, Mark Wu, MD, Jeffrey O'Donnell, MD, Thorsten Seyler, MD, PhD
Department of Orthopaedic Surgery, Duke University Medical Center, Durham, NC, USA

Purpose: The number of obese patients seeking total hip arthroplasty (THA) continues to expand despite body mass index (BMI) cutoffs. We sought to determine the outcomes of THA in the morbidly obese patient, and hypothesized they would have comparable outcomes to two cohorts of obese, and normal weight patients.
Materials and Methods: THA performed on morbidly obese patients (BMI >40 kg/m^2) at a single academic center from 2010 until 2020 were retrospectively reviewed. Eighty morbidly obese patients were identified, and matched in a 1:3:3 ratio to control cohorts with BMI 30-40 kg/m^2 and BMI <30 kg/m^2. Acute postoperative outcomes and BMI change after surgery were evaluated for clinical significance with univariate and regression analyses. Cox proportional hazard ratio was calculated to evaluate prosthetic joint infection (PJI) and revision surgery through follow-up. Mean follow-up was 3.9 years.
Results: In the acute postoperative period, morbidly obese patients trended towards increased hospital length of stay, facility discharge and 90-day hospital returns. At final follow-up, a higher percentage of morbidly obese patients had clinically significant (>5%) BMI loss; however, this was not significant. Cox hazard ratio with BMI <30 kg/m^2 as a reference demonstrated no significant difference in survival to PJI and all-cause revision in the morbidly obese cohort.
Conclusion: Morbidly obese patients (BMI >40 kg/m^2) require increased resource expenditure in the acute postoperative period. However, they are not inferior to the control cohorts (BMI <30 kg/m^2, BMI 30-40 kg/m^2) in terms of PJI or all-cause revisions at mid-term follow-up.

Key Words: Obesity, Body mass index, Total hip arthroplasty, Weight loss, Revision

INTRODUCTION

A low rate of complications, improved pain and function, and exceptional long-term survivorship has been reported in association with Total hip arthroplasty (THA)[1-4]. Given the success of this procedure, the use of THA has continued to increase throughout the United States. Unfortunately, the incidence of obesity is also increasing among members of the American population. The prevalence has more than doubled since 1970, and many adults in the US are now classified as overweight or obese based on their body mass index (BMI)[5].

Submitted: February 2, 2022 1st revision: March 30, 2022
2nd revision: April 19, 2022 Final acceptance: May 10, 2022
Address reprint request to
Niall Cochrane, MD
(https://orcid.org/0000-0002-0767-0811)
Department of Orthopaedic Surgery, Duke University Medical Center, 2301 Erwin Road, Durham, NC 27710, USA
TEL: +1-301-802-8642
E-mail: niall.cochrane@duke.edu

Obesity is a significant risk factor in the development of osteoarthritis[6]. A higher BMI causes elevation of articular cartilage loading forces which can eventually result in tissue damage. In addition, adipokine, a protein that causes inflammation and degradation of excess cartilage, is released by adipose tissue[7]. Mokdad et al.[8] reported a 400% increase in the prevalence of osteoarthritis for morbidly obese patients. Along with the increasing number of obese patients, development of osteoarthritis in these patients has also increased, as well as the demand for joint arthroplasty. As reported in a recent study, the number of obese patients who underwent THA increased by 7.0% from 2012 to 2017[9]. Of particular importance, an association of obesity with a higher risk of complications following arthroplasty including increased risk of prosthetic joint infection (PJI), early failure requiring revision, poor functional outcomes, and increased use of health care resources has also been reported[10-13].

As a result of the rise in value-based healthcare and bundled reimbursement models, attention has been focused on optimizing surgical outcomes while minimizing the risk of infection, re-admission, and revision surgery[14-16]. With the evolution of reimbursement models, there have been incentives to optimize preoperative modifiable risk factors, including glycemic control, malnutrition, smoking and obesity, in order to decrease postoperative complications[17-19]. In 2013, according to a consensus opinion from the American Association of Hip and Knee Surgeons (AAHKS)[20], delaying total joint arthroplasty (TJA) should be considered for patients with a BMI >40 kg/m^2. This resulted from their systematic review of literature, which found a strong association of obesity with comorbid conditions, putting patients at a higher risk for perioperative complications. As a result of this concern, many institutions have established BMI cut-offs for both hip and knee arthroplasty, and surgeries for morbidly obese patients are delayed or canceled until a lower BMI threshold can be achieved[21]. However, there is some question with regard to the difficulty of weight loss experienced by obese patients prior to surgery, and, according to the literature, few patients are able to maintain weight loss, even after undergoing arthroplasty[21].

Regarding total knee arthroplasty (TKA), based on the current literature, the consensus is that morbid obesity, defined as a BMI $\geq$40 kg/m^2, is the threshold at which most perioperative complications, including infection and revision rates appear to show a considerable increase[20]. However, the data on THA is mixed, and there is much less consensus with regard to a threshold above which there is an increased incidence of complications. Therefore, this study was conducted in order to compare clinical outcomes of THA in the population of morbidly obese patients (Class III obesity, BMI $\geq$40 kg/m^2)[22] to those of two cohorts of patients: obese (Class I-II obesity, BMI $\geq$30 to <40 kg/m^2) and regular weight to overweight (BMI $\geq$18.5 to <30 kg/m^2)[22]. The authors hypothesized that satisfactory results would be obtained for morbidly obese patients in the following three categories: survivorship free of infection and all-cause revision, acute postoperative outcomes including discharge disposition and readmissions, and finally, postoperative change in BMI.

MATERIALS AND METHODS

This retrospective comparative cohort study of patients who underwent THA at Duke University Medical Center between January 2010 and March 2020 was approved by Duke Health Institutional Review Board (No. Pro00104324). All procedures were performed by arthroplasty surgeons who had received fellowship training. All primary THAs performed during the above mentioned timeframe with a BMI of >40 kg/m^2 on the day of surgery were included in the study cohort. Revision and conversion arthroplasty, as well as patients who underwent THA for hip fracture, were excluded. All patients had a minimum two-year opportunity for follow-up. Eighty morbidly obese patients who underwent 83 separate THAs with a mean BMI of 42.2 kg/m^2 on the day of surgery were initially identified. Two additional cohorts were then identified: 240 patients undergoing 273 separate THAs with BMI 30-40 kg/m^2 (mean, 34.5 kg/m^2) and 240 patients undergoing 261 separate THAs with BMI <30 kg/m^2 (mean, 25.5 kg/m^2). The World Health Organization (WHO) criteria were used for classification of BMI: regular weight (BMI $\geq$18.5 to <25 kg/m^2), overweight (BMI $\geq$25 to <30 kg/m^2) class-I obese (BMI $\geq$30 to <35 kg/m^2), class-II obese ($\geq$35 to <40 kg/m^2), and class-III obese ($\geq$40 kg/m^2)[22].

Collection of preoperative baseline demographic data including BMI, height (cm), weight (kg), and Elixhauser comorbidity score was performed. The primary outcome of the study was survivorship free of infection and all cause revision through final follow-up. Electronic medical records (EMR) were used for recording PJI and revisions. Collection of acute postoperative data including length of hospital stay, facility discharge (skilled nursing facility or rehab facility), 90-day emergency department (ED) visit and readmissions was also performed. Finally, the EMR was used for recording postoperative BMI at six months, one year, and most recent follow-up visit. In concordance with U.S. Food and Drug Administration guidelines, BMI change of ≥5% was considered clinically significant[23].

The posterior, direct lateral, or anterolateral approach was used in performance of all THA procedures. Bearing surfaces used included ceramic or cobalt chrome (CoCr) on highly cross-linked polyethylene, as well as metal on metal. All femoral stems used were cementless and either metaphyseal (single or double wedge) or diaphyseal fitting.

A chi-square test was performed for evaluation of categorical data; data are presented as count (percentage), while continuous data were non-parametric and evaluation was performed using a Kruskal–Wallis test. These data are presented as mean±standard deviation. Both unadjusted and adjusted Cox proportional hazard ratio controlling for age, sex, race and Elixhauser score with BMI <30 kg/m^2 as reference were performed for evaluation of survivorship to all-cause revision as a primary end-point. An adjusted logistic regression analysis controlling for patient age, sex, race and Elixhauser score with BMI <30 kg/m^2 as a reference was used for evaluation of facility discharge rates, 90-day ED visits and 90-day readmissions. Finally, an adjusted linear regression analysis controlling for patient age, sex, race and Elixhauser score with BMI <30 kg/m^2 as a reference was performed for evaluation of hospital length of stay. When BMI cohorts were significant predictors for acute postoperative outcomes, a Tukey's HSD (honest significant difference) test was performed for completion of the post hoc analysis. The number required to treat was also calculated in these scenarios and presented as absolute risk reduction. R Studio version 1.1.463 (R Foundation, Vienna, Austria) was used in performance of statistical analysis. Data is presented with 95% confidence intervals and in all cases, $P \leq 0.05$ was considered statistically significant.

RESULTS

1. Demographics

The mean age for the entire cohort was 59 years (range, 19-88 years) and 56.6% of patients were female. The mean follow-up period was 3.9±2.0 years. Other patient demographics are shown in Table 1. Osteoarthritis was the most common indication for surgery in all cohorts. The BMI <30 kg/m^2 cohort included a significantly higher percentage of patients with avascular necrosis (Table 2).

Table 1. Patient Demographics (n=617)

Variable	BMI (kg/m^2)			*P*-value
	<30 (n=261)	30-40 (n=273)	>40 (n=83)	
Age (yr)	58.3±16.0	59.0±10.7	58.4±10.4	0.84
Sex, female	145 (55.6)	157 (57.5)	47 (56.6)	0.90
Patient race (non-Caucasian)	74 (28.4)	75 (27.5)	27 (32.5)	0.67
Elixhauser score	3.4±2.1	3.5±2.0	3.4±1.9	0.95
Follow-up	3.9±2.0	4.1±2.0	3.6±1.9	0.15

Values are presented as mean±standard deviation or number (%).
BMI: body mass index.

Table 2. Surgical Indication When Stratified by Body Mass Index (BMI) Class

Surgical indication	Overall (n=617)	BMI (kg/m^2)			*P*-value
		<30 (n=261)	30-40 (n=273)	>40 (n=83)	
Osteoarthritis	513 (83.1)	197 (75.5)	240 (87.9)	76 (91.6)	0.07
Avascular necrosis	86 (13.9)	58 (22.2)	24 (8.8)	4 (4.8)	0.02*
Hip dysplasia	13 (2.1)	4 (1.5)	6 (2.2)	3 (3.6)	>0.99
Rheumatoid arthritis	3 (0.5)	2 (0.8)	1 (0.4)	0 (0.0)	>0.99
Other	2 (0.3)	0 (0.0)	2 (0.7)	0 (0.0)	>0.99

Values are presented as number (%).
* $P<0.05$.

2. Survivorship Free of Infection and All-Cause Revision

One patient (1.2%) in the BMI >40 kg/m² cohort had a PJI compared to 11 patients (4.0%) in the BMI 30-40 kg/m² cohort and five patients (1.9%) in the BMI <30 kg/m² cohort (*P*=0.21). The unadjusted Cox hazard ratio for PJI compared to patients with BMI <30 kg/m² was 2.13 for BMI 30-40 kg/m² 95% confidence interval (CI) 0.74-6.12 (*P*=0.16) and 0.63 for BMI >40 kg/m² 95% CI 0.07-5.41 (*P*=0.68). When adjusted for patient age, sex, race, and Elixhauser score, BMI 30-40 kg/m² (*P*=0.16) and BMI >40 kg/m² (*P*=0.70) were not significant predictors of PJI. However, the Elixhauser score was a significant predictor of PJI (*P*<0.01). Seven-year survivorship free of PJI is shown in Fig. 1.

Two patients (2.4%) underwent revision surgery in the BMI >40 kg/m² cohort compared to 12 patients (4.4%) in the BMI 30-40 kg/m² group and eight patients (3.1%) in the BMI <30 kg/m² group (*P*=0.59). Time to revision, indication for revision, and BMI of the patient undergoing revision are shown in Table 3. The unadjusted Cox hazard ratio for all cause revision compared to patients with BMI <30 kg/m² was 1.44 for BMI 30-40 kg/m² 95% CI 0.59-3.53 (*P*=0.42) and 0.80 for BMI >40 kg/m² 95% CI 0.17-3.77 (*P*=0.78). When adjusted for patient age, sex, race, and Elixhauser score, BMI 30-40 kg/m² (*P*=0.37) and BMI >40 kg/m² (*P*=0.82) were not significant predictors of all cause revisions. However, the Elixhauser score (*P*=0.01) was a significant predictor of all cause revision. Seven-year survival to all-cause revision is shown in Fig. 2.

3. Hospital Length of Stay and Facility Discharge

There was no significant difference in mean hospital length of stay (*P*=0.31) and facility discharge (*P*=0.34) (Table 4). The results of adjusted linear regression showed that female sex (*P*<0.01), non-Caucasian race (*P*<0.01), and Elixhauser score (*P*<0.01) were predictive of a prolonged hospital stay (Table 5). The adjusted odds ratio demonstrated that age (*P*<0.01), female sex (*P*<0.01), non-Caucasian race (*P*=0.2), and BMI >40 kg/m² (*P*=0.04) were predictive of discharge from the facility (Table 6). The results of post hoc analysis for facility discharge showed

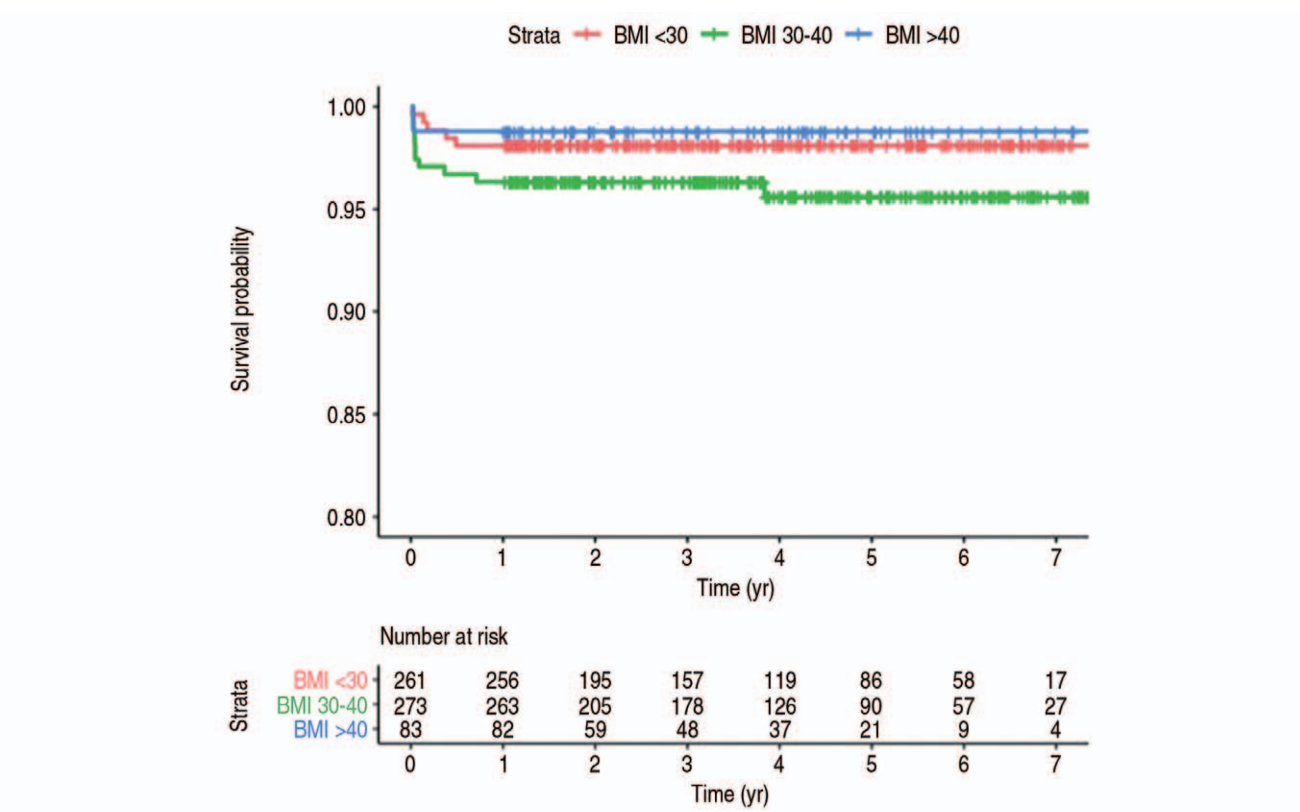

Fig. 1. Kaplan–Meier curve demonstrating seven-year survival to prosthetic joint infection.
BMI: body mass index (unit: kg/m²).

Table 3. All Cause Revisions in All Cohorts

Cohort	BMI (kg/m²)	Time to revision (day)	Reason for revision
Morbidly obese BMI >40 kg/m²	41.2	10	Prosthetic joint infection
	40.4	6	Periprosthetic fracture
	41.1	28	Prosthetic joint infection
Obese BMI 30-40 kg/m²	34.6	8	Prosthetic joint infection
	34.7	10	Prosthetic joint infection
	35.6	14	Prosthetic joint infection
	39.1	15	Prosthetic joint infection
	31.2	17	Prosthetic joint infection
	32.4	17	Prosthetic joint infection
	36.2	32	Prosthetic joint infection
	34.2	119	Aseptic loosening
	39.3	133	Prosthetic joint infection
	38.9	259	Prosthetic joint infection
	32.1	523	Aseptic loosening
	39.2	1,400	Prosthetic joint infection
Non-obese BMI <30 kg/m²	25.2	5	Prosthetic joint infection
	25.1	50	Prosthetic joint infection
	22.2	65	Prosthetic joint infection
	24.9	139	Instability
	29.0	139	Prosthetic joint infection
	24.6	168	Instability
	19.9	686	Aseptic loosening
	19.4	994	Instability
	22.4	2,158	Prosthetic joint infection

BMI: body mass index.

no significant difference between BMI 30-40 kg/m² and BMI <30 kg/m² (*P*=0.47), BMI >40 kg/m² and BMI <30 kg/m² (*P*=0.10), and BMI >40 kg/m² and BMI <30 kg/m² (*P*=0.44). The results of absolute risk reduction showed that 15 patients with BMI >40 kg/m² would have to decrease their BMI to <30 kg/m² preoperatively in order to reduce facility discharges by one patient.

4. 90-Day ED Return and Readmission

There was no significant difference in ED visits (*P*=0.59) or readmissions (*P*=0.59) during the 90-day postoperative period (Table 4). The adjusted odds ratio demonstrated that age (*P*=0.04), female sex (*P*<0.01), and Elixhauser score (*P*<0.01) were predictive of 90-day ED return and age (*P*<0.01), female sex (*P*=0.03), and Elixhauser score (*P*<0.01) were predictive of 90-day readmission (Table 6).

5. Postoperative Weight Change

A significant difference in mean recorded BMI and weight at the time of surgery was observed between the three groups, and remained significantly different until final follow-up (*P*<0.01). The number of patients with >5% change in BMI at six month, one year, and final follow-up is shown in Table 7. Postoperatively, >5% loss of BMI was observed for a higher percentage of patients in the BMI >40 kg/m² cohort at the final follow-up; however, this finding was not statistically significant. The percentage of patients with clinically significant weight loss increased by 21.8% in the morbidly obese cohort from six months to final follow-up (Fig. 3).

DISCUSSION

Many reports examining the relationship between obesity and outcomes for TJA have been published over the past decade. After publication of the AAHKS consensus guidelines on the risks of morbidly obese patients undergoing elective THA or TKA, many practices imposed strict BMI cut-offs, thereby declining to perform or delaying surgery for patients with BMI >40 kg/m² until lower BMI could be achieved. Given the conflicting data found in our review of the literature, the authors determined that further investigation of the relationship between BMI and clinical outcomes was required.

Findings from several registry-based studies and system-

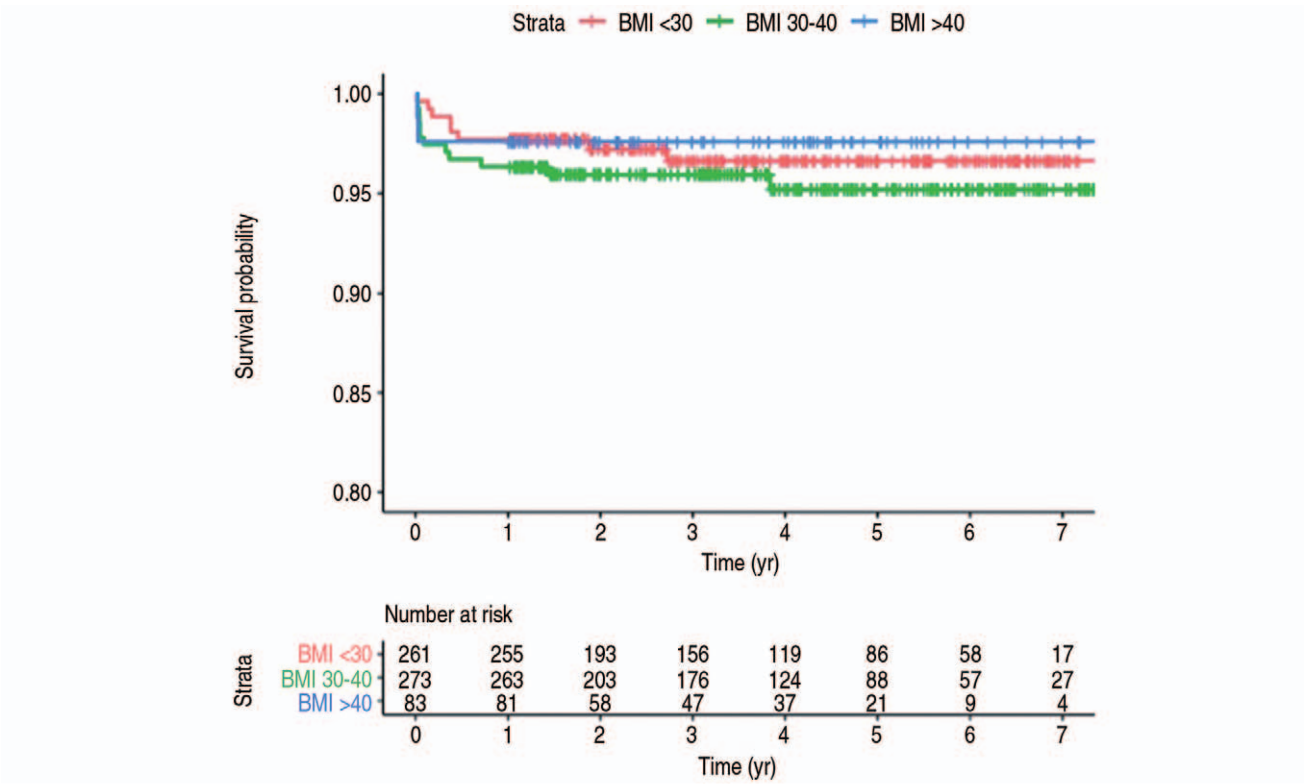

Fig. 2. Kaplan–Meier curve demonstrating seven-year survival to all-cause revision.
BMI: body mass index (unit: kg/m^2).

Table 4. Univariate Analysis of Acute Postoperative Outcomes (n=617)

Variable	BMI (kg/m^2)			*P*-value
	<30 (n=261)	30-40 (n=273)	>40 (n=83)	
Mean length of stay (day)	2.5	2.4	2.7	0.31
Facility disposition (%)	13.8	16.1	20.5	0.34
Revision any reason, n (%)	8 (3.1)	12 (4.4)	2 (2.4)	0.59
Prosthetic joint infection, n (%)	5 (1.9)	11 (4.0)	1 (1.2)	0.21
90-Day ED visit, n (%)	23 (8.8)	23 (8.4)	10 (12.0)	0.59
90-Day readmission, n (%)	14 (5.4)	18 (6.6)	7 (8.4)	0.59

BMI: body mass index, ED: emergency department.

Table 5. Adjusted Linear Regression Analysis Evaluating Predictors of Increased Length of Hospital Stay

Variable	Estimate	Standard error	*P*-value
Age	<–0.01	<0.01	0.83
Sex, female	0.40	0.14	<0.01*
Non-Caucasian race	0.44	0.15	<0.01*
Elixhauser score	0.29	0.04	<0.01*
BMI 30-40 kg/m^2	–0.12	0.14	0.42
BMI >40 kg/m^2	0.22	0.21	0.29

BMI: body mass index.
* $P<0.05$.

Table 6. Adjusted Logistic Regression Evaluating Predictors of Facility Discharge, 90-Day ED Visits and Readmissions

	Mean±SD	%	Odds ratio	95% CI	*P*-value
Facility discharge					
Age	58.4±13.3	-	1.06	1.04-1.09	<0.01*
Sex, female	-	78	2.58	1.52-4.52	<0.01*
Non-Caucasian race	-	37	1.9	1.10-3.26	0.02*
Elixhauser score	3.5±2.0	-	1.31	1.15-1.48	<0.01*
BMI 30-40 kg/m^2	-	42	1.38	0.81-2.36	0.24
BMI >40 kg/m^2	-	18	2.09	1.02-4.20	0.04*
90-Day ED visit					
Age	58.2±13.6	-	0.98	0.95-1	0.04*
Sex, female	-	77	3.08	1.61-6.27	<0.01*
Non-Caucasian race	-	42	1.41	0.75-2.59	0.28
Elixhauser score	3.5±2.1	-	1.41	1.22-1.63	<0.01*
BMI 30-40 kg/m^2	-	46	0.98	0.52-1.85	0.95
BMI >40 kg/m^2	-	17	1.52	0.65-3.39	0.32
90-Day readmission					
Age	58.0±13.7	-	0.94	0.91-0.96	<0.01*
Sex, female	-	61	2.28	1.11-4.94	0.03*
Non-Caucasian race	-	39	0.91	0.43-1.86	0.80
Elixhauser score	3.5±2.1	-	1.42	1.2-1.68	<0.01*
BMI 30-40 kg/m^2	-	43	1.6	0.74-3.58	0.24
BMI >40 kg/m^2	-	17	2.07	0.73-5.55	0.16

ED: emergency department, BMI: body mass index, SD: standard deviation, CI: confidence interval.
* *P*<0.05.

Table 7. BMI Change at 6-Month, 1-Year, and Final Follow-Up

Variable	n	BMI (kg/m^2)			*P*-value
		<30 (n=283)	30-40 (n=296)	>40 (n=90)	
Time of total hip arthroplasty (n=617)					
BMI at surgery (kg/m^2)		25.5±2.8	34.5±2.7	42.2±1.9	<0.01*
Weight at surgery (kg)		92.0±21.8	100.1±14.8	121.0±16.4	<0.01*
6-Month follow-up (n=603)					
>5% BMI gain	73 (12.1)	33 (12.9)	31 (12.0)	8 (9.9)	0.79
No change	429 (71.1)	176 (69.0)	191 (71.5)	62 (76.5)	-
>5% BMI loss	101 (16.7)	46 (18.0)	44 (16.5)	11 (13.6)	-
1-Year follow-up (n=590)					
>5% BMI gain	70 (11.9)	30 (11.8)	32 (12.3)	8 (10.8)	0.99
No change	355 (60.2)	156 (61.2)	155 (59.4)	44 (59.5)	-
>5% BMI loss	165 (28.0)	69 (27.1)	74 (28.4)	22 (29.7)	-
Final follow-up (n=616)					
>5% BMI gain	88 (14.3)	41 (15.7)	33 (12.1)	14 (17.1)	0.42
No change	342 (55.5)	146 (55.9)	157 (57.5)	39 (47.6)	-
>5% BMI loss	186 (30.2)	74 (28.4)	83 (30.4)	29 (35.4)	-

Values are presented as mean±standard deviation or number (%).
BMI: body mass index.
* *P*<0.05.

atic reviews have demonstrated that a higher BMI can increase the risk of morbidity and mortality, with complications such as bleeding, infection, and dislocation[20]. In a systematic review of eight studies Barrett et al.[24] suggested that there is an increased rate of THA revision in obese patients (BMI >35 kg/m^2). They compared revision out-

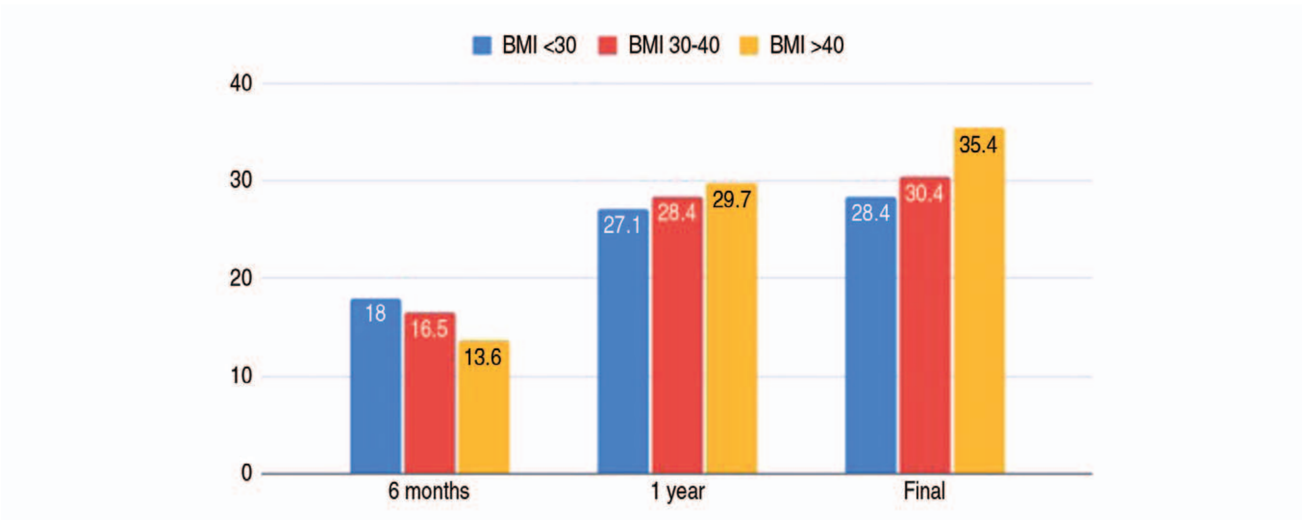

Fig. 3. Percentage of patients in each cohort with clinically significant (>5%) BMI loss at six months postoperatively, one year postoperatively, and final recorded follow-up.
BMI: body mass index (unit: kg/m²).

comes of 66,238 THAs in patients with BMI >35 kg/m² to 705,619 THAs in a non-obese control group. An average revision rate of 8% was reported for obese patients versus 3% for non-obese patients[24]. However, of the eight reviewed studies, only two studies matched the obese and control cohorts, presenting the possibility for confounding variables that were unaccounted for in their analysis. In a review of a large cohort of Medicare patients undergoing THA, Bozic et al.[25] reported that obesity is an independent predictor of PJI. Their data relied on administrative claims which did not specifically define obesity in terms of a BMI cutoff, and instead relied on recorded ICD-9 codes for identification of obese patients. As a result, there was limited control with regard to what constituted an obese patient. In a registry-based study, Namba et al.[26] conducted a review of 1,071 THAs performed on obese patients. According to the authors, a BMI >35 kg/m² showed an association with a higher rate of infection; however, again, there was no control for comorbid conditions between the obese and non-obese groups.

In contrast with the literature described above, some multicenter trials and registry studies have reported more favorable outcomes after THA in the morbidly obese population. A multicenter prospective study of 1,421 patients undergoing THA was conducted by Andrew et al.[27]. The patients were classified into three groups: non-obese (BMI <30 kg/m²), obese (BMI 30-40 kg/m²), and morbidly obese (BMI >40 kg/m²). There were 14 revisions in the non-obese group (1.3%), five revisions in the obese group (1.5%), and no revisions in the morbidly obese group at the five-year follow-up. These differences were not statistically significant. While this study included a large number of enrolled patients, the morbidly obese group (BMI >40 kg/m²) included only 18 patients[27]. In a review of the National Joint Registry (NJR) in England, Wales, Northern Ireland, and the Isle of Man, Mouchti et al.[28] reported a slight increase in revision rates in morbidly obese patients. Of particular interest, lower 90-day all-cause mortality was observed in the morbidly obese population. The authors concluded that revision and mortality rates in the morbidly obese population were acceptable by contemporary standards, and found no evidence to suggest that access to THA should be restricted based on BMI[28].

Of particular interest, most single-center studies have reported no association between BMI and a significant increase in postoperative adverse outcomes. Findings from a single center study of 3,290 patients conducted by McCalden et al.[29] demonstrated that revision rates in morbidly obese patients (BMI >40 kg/m²) were non-inferior to those of the obese, normal weight, and underweight cohorts. However, they did report a significant increase in PJI in their morbidly obese cohort. The authors did not report on acute postoperative outcomes and their cohorts were not matched. In a study conducted by McLaughlin and Lee[30], a cohort of 100 THAs in patients with BMI >30 kg/m² was compared with a cohort of 109 THAs in patients with BMI <30 kg/m². At a mean follow-up of 14 years, five femoral components (1%) were revised and 57 (57%) acetabular components were revised in the obese (BMI >30 kg/m²) cohort. Six (6%) femoral components were revised and 72 acetabular components were revised (66%) in the non-obese group. These differences were not significant and the authors concluded that there is no evidence to support withholding THA from obese patients[30].

Many previous studies examining arthroplasty in an obese population were registry-based, thus there was no effective control for comorbid conditions that affect the population of obese patients. Our data set provides strong, unique evidence that although morbid obesity may result in increased utilization of resources during the acute postoperative period, it alone is not a significant predictor for PJI or revision arthroplasty. In addition, age, female sex, and Elixhauser comorbidity score were independent predictors of unfavorable acute postoperative outcomes. Based on this finding, there is a question regarding the previously recommended guidelines for denying a patient THA based on BMI alone. There may be downstream healthcare costs that would otherwise be incurred by the system due to sustained high BMI if a morbidly obese patient is denied a THA; further evaluation is required.

Several authors have reported on the difficulty of weight loss for obese patients prior to surgery[21,31,32]. Springer et al.[21] reported that most patients in their morbidly obese cohort were unable to achieve a preoperative BMI <40 kg/m^2, and were therefore not able to undergo TJA. Reeves et al.[33] conducted an evaluation of 230 morbid (40-49.9 kg/m^2) and 50 super obese (>50 kg/m^2) patients seeking to undergo TJA. According to the authors, super obese patients were less likely to receive TJA, and each one kg/m^2 increase in BMI decreased the odds of TJA by 10.9%. Of particular interest, other studies found in the literature have demonstrated significant functional improvements following THA in morbidly obese patients[34-36]. Giori et al.[36] conducted an evaluation of obese Veterans Affairs patients who were denied an arthroplasty due to BMI. According to their findings, for every patient with a BMI >40 kg/m^2 who developed a complication following THA or TKA, using a strict cut-off of BMI 40 kg/m^2, 14 patients would be denied a complication-free arthroplasty procedure. Findings from these studies complement our results and provide further evidence that THA should be reconsidered as a viable option for elective surgery in a morbidly obese patient population if indicated.

The number of THAs performed in the population of morbidly obese patients at our academic center was the most significant limitation to our study. Although our institution has a BMI cutoff of 40 kg/m^2 for patients undergoing THA, it can be waved based on surgeon discretion. While the number of patients in each cohort is limited, we believe that our findings are improved by the ability to perform regression analysis for control of cohorts. Finally, this study was a retrospective review of each cohort; therefore, there are inherent disadvantages with regard to the study design. Conduct of further prospective trials will be required in order to provide a true comparison of outcomes between the cohorts.

In addition, when obese and morbidly obese patients were combined, higher incidence of PJI and revision was observed in the combined obese group compared with the normal BMI group. A higher incidence of 90-day ED visits and readmissions was also observed in the combined obese group. Finally, diagnosis of a majority of patients in the obese and morbidly obese cohorts with PJIs was made during the early postoperative period, which might indicate that obesity is a risk factor for early PJI after THA. Based on the findings described above, while the results of this study did demonstrate that morbid obesity alone was not a predictor for inferior outcomes, the results should be interpreted with caution.

CONCLUSION

The findings of this study demonstrate that PJI and revision rates in morbidly obese patients (BMI >40 kg/m^2) undergoing THA are not inferior to those classified by the WHO as normal weight, overweight, Class I or II obesity (BMI <40 kg/m^2). Morbid obesity (BMI >40 kg/m^2) was an independent predictor of discharge from the facility, and a trend towards other inferior early postoperative outcomes including length of hospital stay and 90-day hospital returns was observed for patients in this cohort. However, other variables including age, female sex, and Elixhauser comorbidity score were also independent predictors of increased utilization of resources during the acute postoperative period. A trend towards a higher percentage of patients with clinically significant loss of BMI at the final follow-up was observed for the morbidly obese cohort, which could theoretically result in a decrease of downstream healthcare costs. A higher incidence of revisions, PJI, and 90-day hospital returns was observed when these two cohorts were combined. These findings call into question the practice of restricting THA to patients with a BMI <40 kg/m^2 based on BMI alone; therefore, conduct of further studies will be required, particularly in the setting of a highly successful procedure with relatively lower risk.

CONFLICT OF INTEREST

The authors declare that there is no potential conflict of interest relevant to this article.

REFERENCES

1. Shan L, Shan B, Suzuki A, Nouh F, Saxena A. *Intermediate and long-term quality of life after total knee replacement: a systematic review and meta-analysis. J Bone Joint Surg Am. 2015;97:156-68. https://doi.org/10.2106/JBJS.M.00372*
2. Long WJ, Bryce CD, Hollenbeak CS, Benner RW, Scott WN. *Total knee replacement in young, active patients: long-term follow-up and functional outcome: a concise follow-up of a previous report. J Bone Joint Surg Am. 2014;96:e159. https://doi.org/10.2106/JBJS.M.01259*
3. Learmonth ID, Young C, Rorabeck C. *The operation of the century: total hip replacement. Lancet. 2007;370:1508-19. https://doi.org/10.1016/S0140-6736(07)60457-7*
4. Callaghan JJ, Albright JC, Goetz DD, Olejniczak JP, Johnston RC. *Charnley total hip arthroplasty with cement. Minimum twenty-five-year follow-up. J Bone Joint Surg Am. 2000;82:487-97. https://doi.org/10.2106/00004623-200004000-00004*
5. Flegal KM, Carroll MD, Ogden CL, Johnson CL. *Prevalence and trends in obesity among US adults, 1999-2000. JAMA. 2002;288:1723-7. https://doi.org/10.1001/jama.288.14.1723*
6. Stürmer T, Günther KP, Brenner H. *Obesity, overweight and patterns of osteoarthritis: the Ulm Osteoarthritis Study. J Clin Epidemiol. 2000;53:307-13. https://doi.org/10.1016/s0895-4356(99)00162-6*
7. Pottie P, Presle N, Terlain B, Netter P, Mainard D, Berenbaum F. *Obesity and osteoarthritis: more complex than predicted! Ann Rheum Dis. 2006;65:1403-5. https://doi.org/10.1136/ard.2006.061994*
8. Mokdad AH, Ford ES, Bowman BA, et al. *Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001. JAMA. 2003;289:76-9. https://doi.org/10.1001/jama.289.1.76*
9. Johnson CA, White CC, Kunkle BF, Eichinger JK, Friedman RJ. *Effects of the obesity epidemic on total hip and knee arthroplasty demographics. J Arthroplasty. 2021;36:3097-100. https://doi.org/10.1016/j.arth.2021.04.017*
10. Ward DT, Metz LN, Horst PK, Kim HT, Kuo AC. *Complications of morbid obesity in total joint arthroplasty: risk stratification based on BMI. J Arthroplasty. 2015;30(9 Suppl):42-6. https://doi.org/10.1016/j.arth.2015.03.045*
11. Werner BC, Evans CL, Carothers JT, Browne JA. *Primary total knee arthroplasty in super-obese patients: dramatically higher postoperative complication rates even compared to revision surgery. J Arthroplasty. 2015;30:849-53. https://doi.org/10.1016/j.arth.2014.12.016*
12. Courtney PM, Rozell JC, Melnic CM, Sheth NP, Nelson CL. *Effect of malnutrition and morbid obesity on complication rates following primary total joint arthroplasty. J Surg Orthop Adv. 2016;25:99-104.*
13. Sayeed Z, Anoushiravani AA, Chambers MC, et al. *Comparing in-hospital total joint arthroplasty outcomes and resource consumption among underweight and morbidly obese patients. J Arthroplasty. 2016;31:2085-90. https://doi.org/10.1016/j.arth.2016.03.015*
14. Froemke CC, Wang L, DeHart ML, Williamson RK, Ko LM, Duwelius PJ. *Standardizing care and improving quality under a bundled payment initiative for total joint arthroplasty. J Arthroplasty. 2015;30:1676-82. https://doi.org/10.1016/j.arth.2015.04.028*
15. Iorio R, Clair AJ, Inneh IA, Slover JD, Bosco JA, Zuckerman JD. *Early results of Medicare's bundled payment initiative for a 90-day total joint arthroplasty episode of care. J Arthroplasty. 2016;31:343-50. https://doi.org/10.1016/j.arth.2015.09.004*
16. Clair AJ, Evangelista PJ, Lajam CM, Slover JD, Bosco JA, Iorio R. *Cost analysis of total joint arthroplasty readmissions in a bundled payment care improvement initiative. J Arthroplasty. 2016;31:1862-5. https://doi.org/10.1016/j.arth.2016.02.029*
17. Malinzak RA, Ritter MA, Berend ME, Meding JB, Olberding EM, Davis KE. *Morbidly obese, diabetic, younger, and unilateral joint arthroplasty patients have elevated total joint arthroplasty infection rates. J Arthroplasty. 2009;24(6 Suppl):84-8. https://doi.org/10.1016/j.arth.2009.05.016*
18. Pruzansky JS, Bronson MJ, Grelsamer RP, Strauss E, Moucha CS. *Prevalence of modifiable surgical site infection risk factors in hip and knee joint arthroplasty patients at an urban academic hospital. J Arthroplasty. 2014;29:272-6. https://doi.org/10.1016/j.arth.2013.06.019*
19. Boraiah S, Joo L, Inneh IA, et al. *Management of modifiable risk factors prior to primary hip and knee arthroplasty: a readmission risk assessment tool. J Bone Joint Surg Am. 2015;97:1921-8. https://doi.org/10.2106/JBJS.N.01196*
20. Springer BD, Parvizi J, Austin M, et al. *Obesity and total joint arthroplasty: a literature based review. J Arthroplasty. 2013;28:714-21. https://doi.org/10.1016/j.arth.2013.02.011*
21. Springer BD, Roberts KM, Bossi KL, Odum SM, Voellinger DC. *What are the implications of withholding total joint arthroplasty in the morbidly obese? A prospective, observational study. Bone Joint J. 2019;101-B(7_Supple_C):28-32. https://doi.org/10.1302/0301-620X.101B7.BJJ-2018-1465.R1*
22. National Heart, Lung, and Blood Institute. *Classification of overweight and obesity by BMI, waist circumference, and associated disease risks [Internet]. Bethesda: National Heart, Lung, and Blood Institute [cited 2021 Jul 6]. Available from: https://www.nhlbi.nih.gov/health/educational/lose_wt/BMI/bmi_dis*
23. U.S. Department of Health and Human Services. *Guidance for industry developing products for weight management. Washington, DC: U.S. Department of Health and Human Services; 2007. https://www.fda.gov/media/71252/download*
24. Barrett M, Prasad A, Boyce L, et al. *Total hip arthroplasty outcomes in morbidly obese patients: a systematic review. EFORT Open Rev. 2018;3:507-12. https://doi.org/10.1302/2058-5241.3.180011*
25. Bozic KJ, Lau E, Kurtz S, et al. *Patient-related risk factors for periprosthetic joint infection and postoperative mortality following total hip arthroplasty in Medicare patients. J Bone Joint Surg Am. 2012;94:794-800. https://doi.org/10.2106/JBJS.K.00072*
26. Namba RS, Paxton L, Fithian DC, Stone ML. *Obesity and perioperative morbidity in total hip and total knee arthroplasty patients. J Arthroplasty. 2005;20(7 Suppl 3):46-50. https://doi.org/10.1016/j.arth.2005.04.023*

27. Andrew JG, Palan J, Kurup HV, Gibson P, Murray DW, Beard DJ. *Obesity in total hip replacement. J Bone Joint Surg Br. 2008;90:424-9. https://doi.org/10.1302/0301-620X.90B4.20522*
28. Mouchti S, Whitehouse MR, Sayers A, Hunt LP, MacGregor A, Blom AW. *The association of body mass index with risk of long-term revision and 90-day mortality following primary total hip replacement: findings from the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. J Bone Joint Surg Am. 2018;100:2140-52. https://doi.org/10.2106/JBJS.18.00120*
29. McCalden RW, Charron KD, MacDonald SJ, Bourne RB, Naudie DD. *Does morbid obesity affect the outcome of total hip replacement?: an analysis of 3290 THRs. J Bone Joint Surg Br. 2011;93:321-5. https://doi.org/10.1302/0301-620X.93B3.25876*
30. McLaughlin JR, Lee KR. *The outcome of total hip replacement in obese and non-obese patients at 10- to 18-years. J Bone Joint Surg Br. 2006;88:1286-92. https://doi.org/10.1302/0301-620X.88B10.17660*
31. Duchman KR, Gao Y, Phisitkul P. *Effects of total knee and hip arthroplasty on body weight. Orthopedics. 2014;37:e278-85. https://doi.org/10.3928/01477447-20140225-61*
32. Inacio MC, Kritz-Silverstein D, Paxton EW, Fithian DC. *Do patients lose weight after joint arthroplasty surgery? A systematic review. Clin Orthop Relat Res. 2013;471:291-8. https://doi.org/10.1007/s11999-012-2537-7*
33. Reeves RA, Hefter GD, Pellegrini VD Jr, Drew JM, Barfield WR, Demos HA. *The fate of morbidly obese patients with joint pain: a retrospective study of patient outcomes. J Arthroplasty. 2021;36:3101-7.e1. https://doi.org/10.1016/j.arth.2021.02.069*
34. Xu S, Chen JY, Lo NN, et al. *The influence of obesity on functional outcome and quality of life after total knee arthroplasty: a ten-year follow-up study. Bone Joint J. 2018;100-B:579-83. https://doi.org/10.1302/0301-620X.100B5.BJJ-2017-1263.R1*
35. Chen JY, Lo NN, Chong HC, et al. *The influence of body mass index on functional outcome and quality of life after total knee arthroplasty. Bone Joint J. 2016;98-B:780-5. https://doi.org/10.1302/0301-620X.98B6.35709*
36. Giori NJ, Amanatullah DF, Gupta S, Bowe T, Harris AHS. *Risk reduction compared with access to care: quantifying the trade-off of enforcing a body mass index eligibility criterion for joint replacement. J Bone Joint Surg Am. 2018;100:539-45. https://doi.org/10.2106/JBJS.17.00120*