The Journal of Arthroplasty 31 (2016) 749–753

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Health Policy & Economics

Body Mass Index More Than 45 kg/m^2 as a Cutoff Point Is Associated With Dramatically Increased Postoperative Complications in Total Knee Arthroplasty and Total Hip Arthroplasty

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ARTICLE INFO

Article history:
Received 23 September 2015
Received in revised form
27 October 2015
Accepted 27 October 2015
Available online 10 November 2015

Keywords:
body mass index
cutoff point
complication
total knee arthroplasty
total hip arthroplasty

ABSTRACT

Background: Higher body mass index (BMI) has been associated with postoperative complications in total knee arthroplasty (TKA) and total hip arthroplasty (THA). However, the association of incremental increases of BMI and its effects on postoperative complications has not been well studied. We hypothesize that there is a BMI cutoff at which there is a significant increase of the risk of postoperative complications.

Methods: We studied the American College of Surgeons National Surgical Quality Improvement Program from 2006 to 2013. The final cohort included 77,785 primary TKA and 49,475 primary THA subjects, respectively. Patients were separated into 7 groups based on BMI (18.5-24.9 kg/m^2, 25.0-29.9 kg/m^2, 30.0-34.9 kg/m^2, 35.0-39.9 kg/m^2, 40.0-44.9 kg/m^2, 45.0-49.9 kg/m^2, and >50.0 kg/m^2). We analyzed data on five 30-day composite complication variables, including any complication, major complication, wound infection, systemic infection, and cardiac and/or pulmonary complication.

Results: The odds ratio for 4 (any complication, major complication, wound infection, and systemic infection) of 5 composite complications started to increase exponentially once BMI reached 45.0 kg/m^2 or higher in TKA. Similarly, the odds ratio in 3 (any complication, systemic infection, and wound infection) of 5 composite complications showed similar trends in THA patients. These findings were further confirmed with propensity score matching and entropy balancing.

Conclusions: Our study suggested that there was a positive correlation between BMI and incidences of 30-day postoperative complications in both TKA and THA. The odds of complications increased dramatically once BMI reached 45.0 kg/m^2.

The prevalence of obesity among adults has more than doubled since 1960, increasing from 13.4% to 35.7% in the United States [1,2]. More than 1 in 20 (6.3%) are morbidly obese with body mass index (BMI) of 40 kg/m^2 or higher [3]. There is a robust association of obesity and need of lower extremity reconstructive surgeries, including total knee arthroplasty (TKA) and total hip arthroplasty (THA) [4-6], which highlights the need for evaluations regarding postoperative outcomes among this population.

TKA and THA represent highly successful and cost-effective treatments for patients with advanced osteoarthritis of the knee and hip joints [7]. However, the effect of obesity on postoperative complications in TKA and THA has long been debated. Studies have shown both supportive and discouraging results on surgical treatment of terminal arthritis with TKA and THA for obese patients [8-12]. Although obesity is considered a modifiable risk factor by

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to http://dx.doi.org/10.1016/j.arth.2015.10.042.

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http://dx.doi.org/10.1016/j.arth.2015.10.042
0883-5403/

some surgeons, the terminal arthritis condition of obese patients does limit their ability for effective weight loss, and thus presents a paradigm for strategic management.

The World Health Organization (WHO) definition based on BMI categorizes patients into normal (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2), obese (30.0-34.9 kg/m^2), severely obese (35.0-39.9 kg/m^2), morbidly obese (40.0-44.9 kg/m^2), and super obese (>45.0 kg/m^2). Higher BMI has been suggested to be more likely associated with poor surgical outcome and postoperative complications. However, previous reports usually studied BMI as a categorical discrete variable with one cutoff value, commonly at 30 kg/m^2, 35 kg/m^2, or 40 kg/m^2 [8,9,13-15]. This is presumably due to the limitation of smaller sample sizes, which from a statistical perspective limit the fragmentation into multiple groups in the setting of low incidence outcomes. BMI as a continuous variable in the context of its association with postoperative complications therefore remains understudied.

To address this issue, we accessed the large National Surgical Quality Improvement Program (NSQIP) database to study the effects of BMI as a more continuous parameter on TKA and THA. We categorized BMI into 7 bins with smaller ranges according to the WHO definition (18.5-24.9, 25.0-29.9, 30.0-34.9, 35.0-39.9, 40.0-44.9, 45.0-49.9, and ≥50.0 kg/m^2), and then, studied the effect of BMI as a continuous categorical variable. We hypothesize that we could identify a cutoff point for BMI at which there is a significant increase of postoperative complications.

Material and Methods

This study was exempted by the institutional review board.

Study Sample

We acquired the data set from the American College of Surgeons NSQIP from 2006 to 2013 (http://site.acsnsqip.org). The NSQIP prospectively collects data of over 140 variables under a standardized protocol. The data include demographic information, comorbidities, preoperative laboratory results, intraoperative variables, and 30-day postoperative complications. To define our study cohort, we only included patients with the principal Current Procedural Terminology (CPT) code for primary TKA (CPT 27447) or primary THA (CPT 27130). There were a total of 81,835 and 51,961 entries, respectively. We first excluded patients categorized as "emergency," American Society of Anesthesiologist (ASA) Class 4, and ASA Class 5. We then excluded patients with bilateral TKA and bilateral THA as defined by the relevant concurrent CPT code. We next excluded patients with missing information on BMI or BMI <18.5 kg/m^2. We intentionally excluded underweight patients in the present study because of the small number of patients, and mainly our interest on effect of higher BMI on postoperative complications. The final cohort included 77,785 and 49,475 subjects for TKA and THA, respectively (Figs. 1 and 2).

Study Variables

Patients were separated into 7 groups based on BMI (18.5-24.9 kg/m^2, 25.0-29.9 kg/m^2, 30.0-34.9 kg/m^2, 35.0-39.9 kg/m^2, 40.0-44.9 kg/m^2, 45.0-49.9 kg/m^2, and >50.0 kg/m^2). We analyzed data on 5 composite complication variables, including any complication, major complications, wound infection, systemic infection, and cardiac and/or pulmonary complications. The full lists of composite complications were summarized in Table 1. All analyses without specification treated the normal BMI group (18.5-24.9 kg/m^2 subjects) as control.

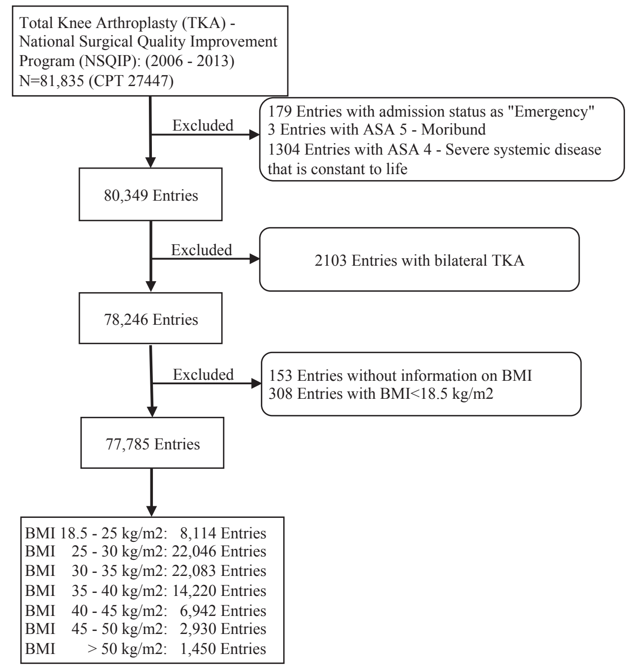

Fig. 1. Flowchart of primary total knee arthroplasty patient selection process. ASA, American Society of Anesthesiologist; BMI, body mass index.

Statistical Analysis

Data analysis was executed using STATA 12.1 statistical software (StataCorp LP, College Station, TX). To examine the impact of BMI on perioperative complication, 3 analyses were conducted. First, we ran multivariate logistic regression analysis on 5 study variables. They were binary variables that equal 1 if the patient experienced (1) any form of complication, (2) major complication, (3) systemic infection, (4) wound infection, or (5) cardiac pulmonary complication. Our key

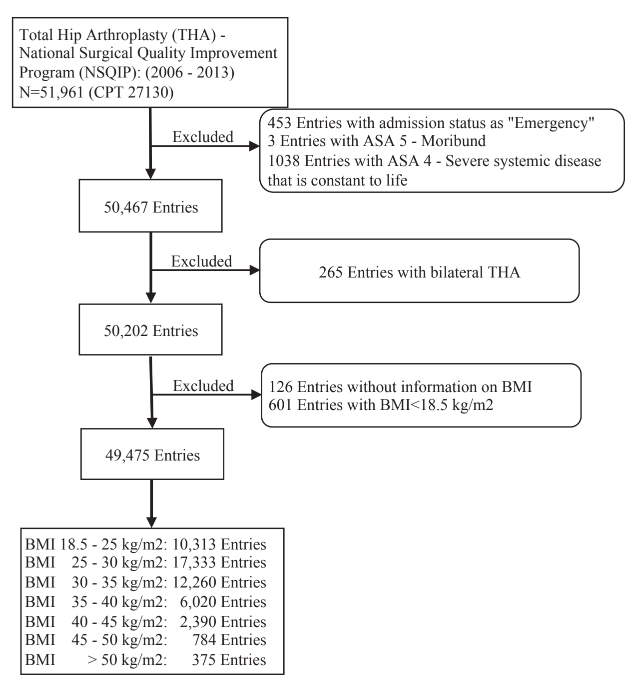

Fig. 2. Flowchart of primary total hip arthroplasty patient selection process.

Table 1
Components of 5 Composite Complications.

Composite Complications	Any Complication	Major Complication	Systemic Infection	Wound Infection	Cardiac Pulmonary Complication
Superficial incisional SSI	+		+	+	
Deep incisional SSI	+		+	+	
Organ space SSI	+		+	+	
Wound disruption	+		+	+	
Pneumonia	+		+		
Unplanned intubation	+	+			+
Pulmonary embolism	+	+			+
On ventilator >48 h	+	+			+
Progressive renal insufficiency	+	+			
Acute renal failure	+	+			
Urinary tract infection	+		+		
Stroke/CVA	+	+			
Coma >24 h	+	+			
Peripheral nerve injury	+				
Cardiac arrest requiring CPR	+	+			+
Myocardial infarction	+	+			+
Graft/prosthesis/flap failure	+				
DVT requiring therapy	+				
Sepsis	+	+	+		
Septic shock	+	+	+		

CPR, cardiopulmonary resuscitation; CVA, cerebrovascular accident; DVT, deep vein thrombosis; SSI, surgical site infection.

independent variable under investigation was BMI groups (range, 1-7) with BMI 18.5-24.9 kg/m^2 subjects as the control, plus 6 confounding variables including age, gender, race, Charlson score, ASA classification, and the year of operation. For each complication type, we plotted the adjusted odds ratio (OR) and 95% CI.

Second, we used the propensity score matching (PSM) method to reflect the probability of having BMI ≥45 after adjusting for the 6 confounders. In matching the treated group (BMI ≥45.0 kg/m^2) and the control group (BMI 18.5-39.9 kg/m^2), we used the kernel matching algorithm where all treated subjects were matched based on the weighted average of all controls, and the weights are inversely proportional to the distance between the propensity scores of the treated and the controls. Using this method, we computed and reported the average treatment effects, that is, the average effect of BMI ≥45.0 kg/m^2, for each complication type.

Third, one key limitation that lies with the PSM method is that it often fails to find a satisfactory balancing solution because it is sensitive to the model specification and the sample size. Under the PSM, low balance levels on extreme values of the propensity score are possible, and it may induce bias in the treatment effect estimation. In light of this, we used a recently developed approach known as the entropy balancing (EB) approach to balance the treatment and the control group [16,17]. The rationale behind the approach is straightforward; the approach uses a reweighting scheme to ensure that the prespecified moments of covariates for the treated group and the control group are matched almost exactly. In general, the EB approach is superior to PSM approach as the former does not rely on the model specification, and it allows researchers to match the higher moments of the covariate distributions between the 2 groups while retaining all samples to ensure no loss of efficiency. Research has shown in Monte Carlo simulations that the EB approach has generated a lower root mean squared error compared to the PSM with different matching algorithms [16]. We used the EB approach as our final statistical approach to examine the impact of BMI on perioperative complication of TKA and THA. The EB approach was used to derive a set of weights to match the mean, the standard deviations and the skewness of covariates including age, gender, race, Charlson score, ASA class, and operation year between the 2 groups. These weights would then be applied in the multivariate logistic regressions. For each complication type, adjusted OR and the corresponding *P* value were reported.

Results

Using BMI 18.5-24.9 kg/m^2 as the baseline, Figure 3A-E presented the ORs and corresponding 95% CI for 5 composite complications after the primary TKA across 7 BMI groups. ORs were gradually increasing along with increase of BMI, but they were insignificantly different from baseline for BMI ≤45.0 kg/m^2. For patients with BMI >45.0 kg/m^2, the ORs were statistically significantly greater than the baseline for most composite complications (any complication, major complication, wound infection, and systemic infection). In particular, the odds of having wound infection for super obese patients after TKA was almost 2 times the odds for the normal weight control group.

Figure 3F-J presented ORs of complications after primary THA. With the exception of major complication and cardiac pulmonary complication, the ORs also were progressively increased along with increasing BMI. The ORs were close to baseline at one and had exhibited a considerable jump for BMI 45.0-49.9 kg/m^2 group. The odds of having wound infection after THA increased from around 1.5 times for morbidly obese patients to almost 2 times in super obese patients than normal patients. The OR was more than 4 times for patients with BMI exceeding 50.0 kg/m^2.

To examine this further, we separated the patients into 2 groups. Using the group of patients with BMI of 18.5-40.0 kg/m^2 as the control group, we studied whether the group of patients with BMI exceeding the cutoff of 45.0 kg/m^2 has significantly higher odds of 30-day postoperative complications after adjusting for confounding variables. Table 2 reported results of multivariable logistic regression analysis, PSM, and EB technique. They all produced results that were qualitatively similar. For TKA, the odds of having any complication or any major complication for the super obese group was 43%-44% higher than the corresponding odds for the control group ($P < .0001$ and $P = .0042$, respectively). The odds of having systemic infection was around 62% higher ($P < .0001$), whereas the odds of having wound infection was 73% higher ($P < .0001$) than that for the control group. For THA, results were similar except that (1) the odds were generally higher and (2) the odds of having major complication was not significantly different between the 2 groups as shown in TKA patients. Consistent with Figure 3, neither TKA nor THA had higher odds of cardiac pulmonary complication after the surgery with BMI >45.0 kg/m^2.

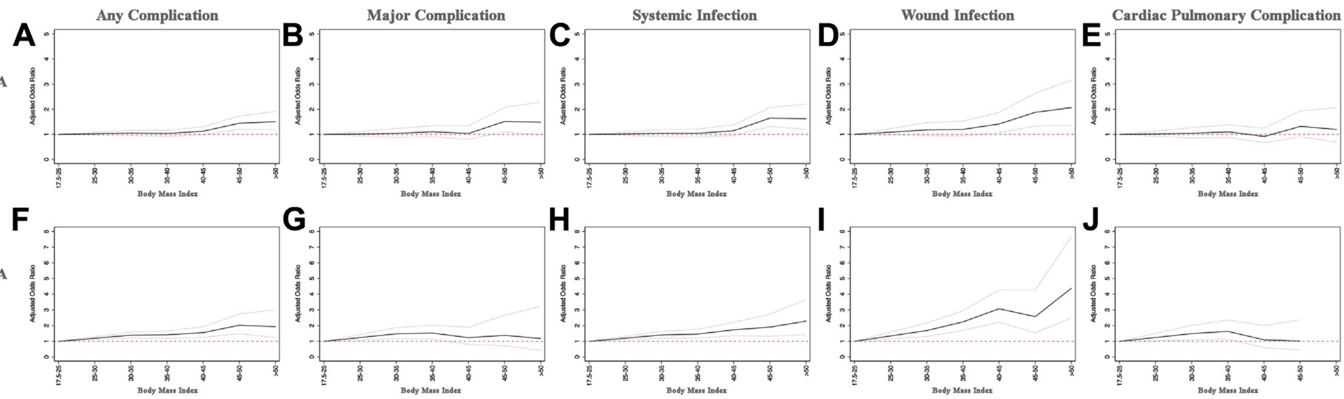

Fig. 3. The figure shows odds ratios (ORs, solid black line) with 95% CIs (dotted black line) for 5 composite complications in total knee arthroplasty (TKA) and total hip arthroplasty (THA) patients. Red dashed line is the baseline control at 1.0 from patients with BMI 18.5-24.9 kg/m^2. Because of limited events in (J), OR and CI could not be calculated for cardiac and/or pulmonary complication in THA among patients with BMI >50 kg/m^2. (A) Any complication in TKA; (B) Major complication in TKA; (C) Systemic infection in TKA; (D) Wound infection in TKA; (E) Cardiac pulmonary complication in TKA; (F) Any complication in THA; (G) Major complication in THA; (H) Systemic infection in THA; (I) Wound infection in THA; (J) Cardiac pulmonary complication in TH.

Discussion

Our study of the American College of Surgeons NSQIP database from 2006 to 2013 showed that there was a positive association between increased BMI and 30-day postoperative complications in both TKA and THA. The odds of complications increased dramatically once BMI surpassed 45.0 kg/m^2. Further consideration of the risks and benefits for surgical treatment with TKA or THA among super obese patients is warranted.

Obesity is a pandemic phenomenon that is drawing increasing attention throughout media. Currently, 24%-36% of patients presenting for THA are classified as obese [18]. The impact of obesity on perioperative outcomes has been long debated. Studies have evaluated the impact on blood loss, operating time, dislocation rates, hematoma formation, infections, and other complications [15,18-21]. One large study evaluated 40,919 Medicare patients and concluded that obesity was associated with increased risk of periprosthetic joint infection after THA, with no differences in 90-day postoperative mortality [22]. Friedman et al [15] specifically evaluated the effects of morbid obesity (BMI >40 kg/m^2) on complication rates after THA and TKA, and they found increased rates of blood transfusion and infection without differences in bleeding events. Nonetheless, these studies evaluated a specific cutoff point for BMI to categorize patients and conducted studies thereafter, commonly with BMI 30 kg/m^2 [10,23,24], BMI 35 kg/m^2 [9,19,25], or BMI 40 kg/m^2 [8,13-15].

Although there are raising concerns regarding performance of TKA or THA in obese patients, it has been argued that the relatively low frequency of complications should not preclude surgical treatment based on the presence of obesity alone [26]. To the best of our knowledge, there is no study of obesity while treating BMI as a continuous variable to attempt to identify a tipping point of perhaps unacceptably high risk. We took advantage of the large high-quality NSQIP data set and studied BMI in 7 consecutive categories. Our analysis indicated that there is potentially a tilting point of BMI at 45.0 kg/m^2, at which the risks of complications are increased markedly. We studied both TKA and THA in parallel, by which we expected these 2 independent analyses could serve as validation tool for each other.

Our study has several limitations. First, our study is limited by the retrospective analysis of NSQIP data, although NSQIP data were prospectively collected with strict rigorous quality control. Second, NSQIP only collects 30-day postoperative complications. Although this is the best available data set for us to study postoperative complications, longer term outcomes and complications beyond 30 days could not be evaluated. Third, we grouped patients into 7 bins according to the WHO definition. However, further grouping of subjects could not be conducted because of the small number of subjects, especially for the high BMI groups. The grouping strategy in our study thus actually limited our capability to identify a specific numeric cutoff point of BMI, although such cutoff point might not exist in reality. Nonetheless, our study indicated a tilting point of BMI around 45.0 kg/m^2, although the complications are already trending up moderately once BMI is at or above 40.0 kg/m^2. Finally, our study is limited by the available information collected in NSQIP data set. Additional interesting complications specific to joint arthroplasty,

Table 2
Effects of Morbidly Obese (BMI ≥45) on Postoperative Complication in TKA and THA.[a]

Complication Type	Logic Regression[b]		Propensity Score Matching[c]		Entropy Balancing Matching[d]	
	Odds Ratio	*P* Value	Treatment Effect	*P* Value	Odds Ratio	*P* Value
Panel A: TKA						
Any complication	1.4250	<.0001	0.0169	<.0001	1.4436	.0019
Major complication	1.4394	.0042	0.0057	.0142	1.5005	.0185
Systemic infection	1.6158	<.0001	0.0137	<.0001	1.5971	.0017
Wound infection	1.7257	<.0001	0.0075	.001	1.7063	.0059
Cardiac pulmonary complication	1.2266	.1934	0.0025	.1783	1.3071	.1460
Panel B: THA						
Any complication	1.6622	.0001	0.0264	.0008	1.6706	.0057
Major complication	1.0439	.8774	−0.0001	.9791	0.9633	.8981
Systemic infection	1.6644	.0004	0.0208	.0026	1.6649	.0112
Wound infection	2.2313	<.0001	0.0183	.0007	2.2448	.0044
Cardiac pulmonary complication	0.7745	.5424	−0.0023	.3247	0.6823	.3854

ASA, American Society of Anesthesiologist; BMI, body mass index; THA, total hip arthroplasty; TKA, total knee arthroplasty.

[a] The control group is BMI 18.5-40 kg/m^2.

[b] Logistic regression is adjusted for age, gender, race, Charlson score, ASA class, and operation year.

[c] Matching is conducted using kernel matching algorithm on variables including age, gender, race, Charlson score, ASA class, and the operation year.

[d] Matching is conducted using the entropy balancing developed by Hainmueller (2011), which essentially assigns weights to the control group so that the moments (mean, standard deviation, and skewness) of the covariate for the control group matches with the moments of the covariates of the treatment group. The covariates are age, gender, race, Charlson score, ASA class, and operation year. Based on these weights, we use the logistic regression to compute the odds ratio.

such as early mechanical failure including fracture or dislocation and incidence of deep prosthetic joint infection, are not captured while these could be of particular relevance in TKA and THA.

Conclusion

We studied primary TKA and primary THA patients in NSQIP with a specific question of whether there is a cutoff point of BMI that is associated with marked increased risks of postoperative complications. Our study suggested that there was a positive correlation between BMI and incidences of 30-day postoperative complications in both TKA and THA. The odds of complications increased dramatically once BMI reached 45.0 kg/m^2. Further consideration of risk and benefit for surgical treatment with TKA or THA among super obese patients is therefore recommended.

Acknowledgments

The authors would like to thank Lee A. Fleisher, MD for his valuable insight in the study.

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