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A Novel Method for Stratification of Major Complication Risk Using Body Mass Index Thresholds for Patients Undergoing Total Hip Arthroplasty: A National Cohort of 224,413 Patients

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ABSTRACT

Introduction: Elevated body mass index (BMI) is associated with complications following Total Hip Arthroplasty (THA). Since obese individuals are almost 10 times more likely to require THA compared to non-obese individuals, we need to understand the risk-benefit continuum while considering THA in obese patients. We aimed to determine data-driven thresholds for BMI at which the risk of major complications following THA increases significantly.

Methods: Patients were identified in a national database who underwent primary THA from 2010 to 2020. BMI thresholds were identified using the stratum-specific likelihood ratio (SSLR) methodology, which is an adaptive technique that allows for identification of BMI cut-offs, at which the risk of major complications is increased significantly . BMI cutoffs identified using SSLR were used to create a logistic regression model.

Results: A total of 224,413 patients were identified with a mean age of 66 ± 10, BMI 32 ± 6.7, and 7,186 (3%) sustained a major complication. BMI thresholds were defined as 19-31, 32-37, 38-49 and 50+. Overall, the absolute risk of major complications increased from 2.9% in the lowest BMI strata to 7.5% in the highest BMI strata. Compared to patients with a BMI between 19-31, the odds of sustaining a major complication sequentially increased by 1.2, 1.6, and 2.5-times for patients in each higher BMI strata (all, $P < .05$).

Conclusions: We have identified BMI cutoffs using SSLR that categorizes patients into four categories of risk for major complications in a nationally representative patient sample. These thresholds can be used in the surgical decision-making process between patients and surgeons.

Patients with elevated Body Mass Index (BMI) are subject to higher forces applied to articular cartilage and increased adipose-tissue driven inflammation, leading to increased rates of osteoarthritis [1]. As a result of these pathophysiologic risk factors, patients with a BMI over 40 years have been shown to be 8.5 times more likely to require Total Hip Arthroplasty (THA) compared to non-obese patients [2]. It has also been well-demonstrated that obesity is a risk factor for adverse outcomes following THA, including wound infection, aseptic loosening, wound infection, and hospital re-admission [3,4]. These adverse outcomes following THA contribute to the increased overall healthcare costs for this demographic [5]. Despite the potential for adverse outcomes and increased healthcare costs, many authors suggest that patients with elevated BMI should not be denied access to surgery which may markedly improve physical function and quality of life [6–8].

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The World Health Organization has previously declared obesity as a global epidemic and has also recommended classification of obesity into several groups based on round-number BMI cutoffs [9]. As a result, many studies analyzing the relationship between BMI and postoperative outcomes following total joint arthroplasty have utilized the BMI cut-offs previously published and popularized by the World Health Organization [4,9,10]. Given that BMI is a continuous variable, we feel that an adaptive approach on determining BMI cut-offs is most appropriate for informing future risk-benefit analysis for decision-making in caring for patients who are candidates for THA. Moreover, as surgical techniques, anesthesia, and postoperative care continuously improve over time, the risk-benefit relationship between BMI and adverse outcomes following THA should be continuously scrutinized and re-examined. Thus, the purpose of this study was to determine empiric BMI cut-offs that predict varying risk of major complications following THA using a large national cohort and recent data over the past 10 years.

Methods

Patient Sample

Patients were identified through the American College of Surgeons National Safety and Quality Improvement Program (NSQIP) database, a prospectively maintained registry of patients undergoing surgical procedures throughout the United States. NSQIP reports 135 variables including preoperative demographic data, laboratory values, intraoperative data, inpatient complications, as well as 30-day postoperative complications and mortality. In audits of the NSQIP data, disagreement has been shown to be less than 1.8% between raters [11]. Because NSQIP only releases de-identified patient information, this study was exempted from institutional review board approval.

Patient Selection: Inclusion/Exclusion

Patients were identified using Current Procedural Terminology code 27130 to identify patients older than 18 years of age undergoing primary THA for osteoarthritis. Patients were excluded with an indication of trauma, or malignancy. BMI was calculated using the standard formula weight (Kg)/(height(M))^2, with values rounded to the nearest whole integer. 4,857 patients were excluded who had a BMI below the 1st percentile or above the 99th percentile. Data were utilized from 2010-2020, with 224,413 patients included in the final analysis.

Major Complications

Major complications were defined as prosthetic dislocation requiring admission, periprosthetic fracture, surgical site infection requiring hospital admission, hematoma, pulmonary embolism, deep venous thrombosis, sepsis, pneumonia, cardiac arrest, myocardial infarction, re-intubation, renal failure, mortality, or any postoperative complication requiring hospital readmission within 30-days. This classification is in accordance with previous studies using NSQIP studying total joint arthroplasty [12].

Statistical Analysis

SSLRs and 95% confidence intervals (CI) were calculated for the likelihood of major complications occurring with BMI as the independent variable. SSLR is an adaptive technique that allows for identification of BMI cut-offs which optimize differences in the likelihood of major complications. The methodology was originally developed by Pierce and Cornell in 1993 [13] and uses likelihood ratio as its basis. The likelihood ratio indicates how much more likely or less likely a specific "test result" (in this case having a major complication) is in certain individuals with or without a certain predisposition (above or below a certain BMI threshold). Likelihood ratios were calculated for each BMI value in our patient population, and the stratum were subsequently merged using an iterative methodology to ultimately identify BMI cut-offs which optimize differences in major complication risk. BMI cutoffs identified using SSLR were then used to create a logistic regression model to predict major complication risk, adjusting for age, gender, race, American Society of Anesthesiology classification, smoking status, and functional independence. In recent years, SSLR methodology has been more widely adopted in the orthopedic literature [14,15].

Table 1
Baseline Patient Characteristics, N = 224,413 Patients.

Characteristics	N (%)	Mean ± SD
Age		65 ± 11
Male sex	99,180 (45)	
BMI		30 ± 6.0
SSLR19-31	139,904 (64)	
SSLR32 − 37	53,783 (24)	
SSLR38 − 49	26,058 (12)	
SSLR50+	557 (0.3)	
Smoking history	25,586 (13)	
Diabetes	26,311 (12)	
COPD	8,735 (4.0)	
CHF	715 (0.3)	
History of myocardial infarction	15 (0.1)	
Hypertension	122,395 (56)	

BMI, body mass index; SSLR, stratum-specific likelihood ratio; COPD, Chronic Obstructive Pulmonary Disease; CHF, Congestive heart failure; SD, standard deviation.

Results

Demographic and Surgical Characteristics

In total, 224,413 patients were included in this study, with a mean age and BMI of 66 ± 10 year old and 32 ± 6.7, respectively. In terms of demographic and comorbid information, 99,180 (45%) of patients were male; 28,586 (13%) had a history of smoking; 26,311 (12%) were diabetic; 8,735 (4.0%) had a history of chronic obstructive pulmonary disease; 715 (0.3%) had a history of congestive heart failure; 15 (0.006%) had a history of myocardial infarction; and 122,395 (56%) had a history of hypertension (Table 1).

Table 2
Major Complications Among all Patients Undergoing Primary THA.

Complication	N (%)
Major complication	7,186 (3.3)
30-d readmission related to the surgical procedure, unspecified diagnosis	2,403 (1.1)
THA dislocation requiring admission	449 (0.2)
Periprosthetic fracture	237 (0.1)
Surgical site infection requiring admission	1,280 (0.6)
Hematoma	109 (<0.1)
Pulmonary embolism	793 (0.4)
DVT requiring readmission	41 (<0.1)
Sepsis	167 (0.1)
Pneumonia	170 (0.1)
Cardiac arrest	191 (0.1)
Myocardial infarction	560 (0.3)
Reintubation	375 (0.2)
Renal failure	124 (0.1)
Mortality	387 (0.2)

THA, total hip arthroplasty; DVT, deep venous thrombosis.

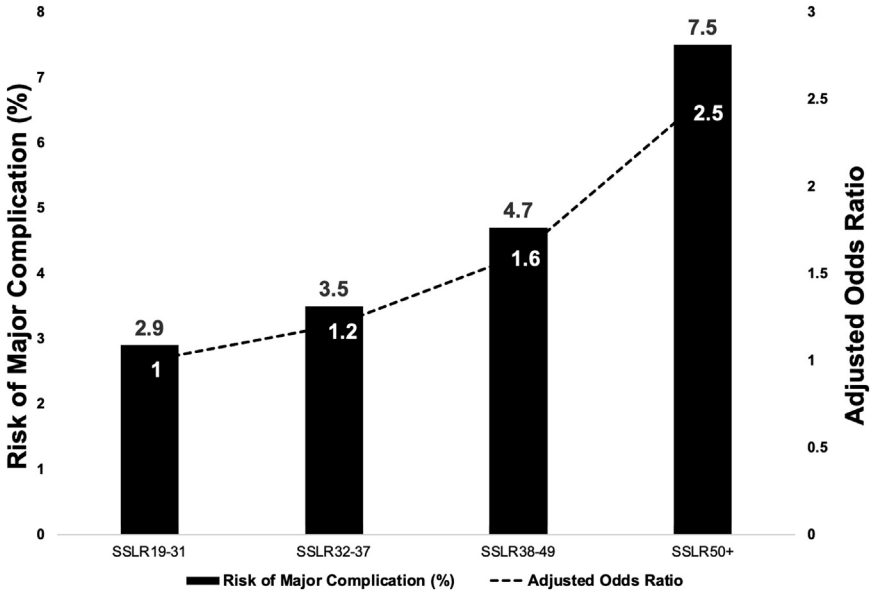

Fig 1.. Risk of a Major Complication Following THA Stratified by BMI Cutoffs. SSLR classification is shown on the X axis with risk of major complication (%) and adjusted odds ratios (OR) shown on the Y axes. Patients were stratified by SSLR BMI threshold including SSLR19-31 (BMI 19-31), SSLR32-37 (BMI 32-37), SSLR38-49 (BMI38-49) and SSLR50+ (BMI 50+). Patients in SSLR19-31 had a 2.9% risk of sustaining a major postoperative complication, while patients in SSLR32-37 had a 3.5% risk (OR 1.2). Patients in SSLR38-49 had a 4.7% risk of a major complication (OR 1.6), and patients in SSLR50 + had a 7.5% risk of a major complication (OR 2.5).

Major Complications

A total of 7,186 (3.3%) patients had at least one major complication. Of these complications, 2,403 (1.1%) had a 30-day readmission due to a postoperative complication without a specified diagnosis, 449 (0.2%) had a readmission for THA dislocation, 237 (0.1%) periprosthetic fractures, 1,280 (0.6%) superficial or deep surgical site infection requiring readmission, 109 (<0.1%) hematoma, 793 (0.4%) pulmonary embolism , 41 (<0.1%) deep venous thrombosis requiring admission, 167 (0.1%) sepsis, 170 (0.1%) pneumonia, 191 (0.1%) cardiac arrest, 560 (0.3%) myocardial infarction, 375 (0.2%) re-intubation for respiratory failure, 124 (0.1%) renal failure requiring dialysis and 387 (0.2%) suffered mortality, cause unspecified (Table 2).

Stratum Specific Likelihood Ratio Analysis

Through SSLR analysis, BMI thresholds were defined as SSLR19-31 (BMI 19-31), SSLR32-37 (BMI 32-37), SSLR38-49 (BMI 38-49) and SSLR50+ (BMI 50+). There were 139,904 total patients in SSLR19-31, 53,783 patients in SSLR32-37, 26,058 patients in SSLR39-49 and 557 patients in SSLR50+.

Overall, 4,063 (2.9%) of patients had a major complication in the SSLR19-31 range, 1,861 (3.5%) of patients had a major complication in the SSLR32-37 group, 1,220 (4.7%) of patients had a major complication in the SSLR38-49 group, and 42 (7.5%) of patients had a major complication in the SSLR50 + BMI group.

Identifying Major Complication Risk Based on SSLR Thresholds

Multivariable logistic regression analysis showed that the odds of major complications increased significantly with each increasing SSLR strata. After controlling for medical comorbidities and demographic covariates, patients with a BMI greater than 50 had the greatest odds of major complications (OR 2.5; 95% CI 1.8-3.4; $P < .001$) when compared to those with a BMI $\leq$31. Patients had 1.2 times greater odds of sustaining a major complication who were in SSLR32-37 vs. SSLR19-31 (95% CI 1.2 − 1.3, $P < .001$). In the SSLR38-49 group, the odds were 1.6 times greater of sustaining a major complication (95% CI 1.5-1.7, $P < .001$) (Table 3, Figure 1).

Discussion

Elevated BMI is known to be associated with increased risk of postoperative complications following THA. Given the increased need for total joint arthroplasty in obese patients, as well as continuous advances in surgical techniques and medical care, we

Table 3
Major Complications, Stratified by SSLR Threshold, Expressed as N (%).

Complication	SSLR19-31, N = 139,904	SSLR32-37, N = 53,783	SSLR38-49, N = 26,058	SSLR50+, N = 557
Pulmonary embolism	335 (0.24)	157 (0.29)	92 (0.35)	3 (0.54)
30-d readmission	3,217 (2.47)	1,572 (3.10)	1,062 (4.32)	39 (7.51)
Deep or superficial surgical site infection	526 (0.38)	388 (0.72)	351 (1.3)	15 (2.7)
Cardiac arrest	126 (0.09)	44 (0.08)	20 (0.08)	1 (0.18)
Myocardial infarction	384 (0.27)	120 (0.22)	55 (0.21)	556 (0.18)
Reintubation	234 (0.17)	92 (0.17)	48 (0.18)	1 (0.18)
Renal failure	60 (0.04)	30 (0.06)	20 (0.08)	2 (0.36)
Mortality	285 (0.20)	65 (0.12)	37 (0.14)	0 (0)

SSLR, indicates stratum-specific likelihood ratio.

felt that it was necessary to identify up-to-date, customized BMI thresholds which predict major, short-term complication risk for patients undergoing THA. Using SSLR analysis, we have identified four BMI categories with increasing risk of major, 30-day postoperative complications. Patients in the highest category had a 5.5% risk of sustaining a major complication and 2.5 times greater odds overall compared to patients in the lowest BMI category.

Perhaps the strongest evidence between elevated BMI and adverse outcomes has been shown with periprosthetic joint infections (PJI) [3,4,10,16]. Recently, the American Academy of Orthopaedic Surgeons determined there is moderate strength evidence to support that obesity is associated with increased risk of PJI, based on 2020 clinical practice guidelines [16]. Among the studies supporting this guideline are works by Lubbeke et. al, who examined prosthetic joint infections following THA and found that patients with BMI between 35-39.9 had a PJI risk twice as high as patients with a lower BMI. In addition, patients with BMI >40 had a four times higher rates of PJI [10]. Similarly, Alvi et. al examined the NSQIP database and found that patients with a BMI >40 had 12.85 times higher rates of deep incision/organ space infection following THA [3].

Subsequent guidelines reflect the findings of these prior investigations. For example, many centers in the United Kingdom restrict total joint arthroplasty to patients less than a BMI of 40 kg/m^2, most likely attributed to works of these past studies [8]. However, in a 2018 study by Giori et. al published in the Journal of Bone and Joint Surgery, the authors investigated the effect of enforcing a strict BMI cutoff of 40kg/m^2 across a large healthcare system. They analyzed 27,671 patients and determined that using this cutoff, 1,148 patients would have been denied a surgery without major complications while 83 patients would have been "saved" from an inevitable major complication according to their data [7]. Thus, the utilization of these prior pre-determined cut-offs in current literature and clinical practice guidelines may be potentially precluding patients from undergoing THA that might actually be safe.

Data from the Cleveland Clinic OME Arthroplasty Group showed that patients with higher BMI have greater absolute improvement in patient-reported outcomes [6]. Moreover, when patients classified as obese undergo THA, they are substantially more likely to lose weight rather than gain it. In a 2015 study by At et. al published in the Journal of Bone and Joint Surgery, the authors examined an institutional registry of 3,893 patients who underwent THA. They found that increasing preoperative obesity was associated with a greater likelihood of postoperative weight loss. In addition, postoperative weight loss was associated with better clinical outcomes scores [17].

Our study has several limitations which should be acknowledged when applying our results to clinical practice. As a retrospective study involving a clinical outcomes database, our results are subject to biases inherent to this study design such as selection bias. BMI is only one component of assessing a patients' postoperative risk following THA, the same way 30-day major complications are only one small component of possible postoperative adverse outcomes following THA. In addition, it should be noted that although NSQIP captures a broad array of surgical complications, arthroplasty-specific complications are not recorded such as aseptic loosening or prosthetic joint infection. These complications are only captured in the present study if they resulted in a hospital readmission within the 30-day postoperative time period. Longitudinal follow-up using other data sources such as registries or insurance claims databases are needed to validate the short-term findings of our study. Ultimately, the risk-benefit analysis of elective THA in an individual patient is exceedingly complicated, and studies like ours are a small part of the shared decision-making process between patients and orthopedic surgeons. We hope that the results of our study help inform this shared decision-making process instead of denying patients with elevated BMI access to care.

Conclusion

Utilizing SSLR analysis, this study identified four empiric BMI cutoffs of $\leq$31, 32-37, 38-49, $\geq$50 which have shown sequential increased risk for 30-day major complications using current data in a nationally representative patient sample. These thresholds may be used in the shared decision-making process with patients and in the development of future clinical practice guidelines for patients undergoing THA.

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