

The Obesity Paradox: A Nonlinear Relationship Between 30-Day Postoperative Complications and Body Mass Index After Total Shoulder Arthroplasty

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ABSTRACT

Background: An inverse relationship coined the “obesity paradox” has been propositioned, in which body mass index (BMI) may be contradictorily protective in patients undergoing surgery or treatment of chronic disease. This study sought to investigate the BMI associated with the lowest rate of medical complications after total shoulder arthroplasty (TSA).

Methods: The American College of Surgeons National Surgical Quality Improvement Project database was queried to identify adults who underwent elective primary TSA between January 2012 and December 2020. Thirty-day postoperative medical complications were extracted, which included death, readmission, pneumonia, pulmonary embolism, renal failure, and cardiac arrest, among others. BMI was classified into five categories (underweight [BMI <18.5 kg/m²], normal weight [BMI ≥18.5 and <25 kg/m²], overweight [BMI ≥25 and <30 kg/m²], obese [BMI ≥30 and <40 kg/m²], and morbidly obese [BMI ≥40 kg/m²]). We examined the risk of any 30-day postoperative complications and BMI categorically and on a continuous basis using multivariable logistic regression controlling for age, sex, procedure year, and comorbidities.

Results: Of the 31,755 TSAs, 84% were White, 56% were female, and the average age of patients was 69.2 ± 9.3 years. Thirty-day postoperative medical complications occurred in 4.53% (n = 1,440). When assessed on a continuous basis, the lowest risk was in patients with a BMI between 30 and 35 kg/m². Underweight individuals (BMI <18.5 kg/m²) had the highest postoperative complication rates overall. The probability of medical complications increased with age and was greater for female patients.

Conclusion: The relationship between BMI and complication risk in TSA is nonlinear. A BMI between 30 and 35 kg/m² was associated with the lowest risk of medical complications after TSA, and BMI <18.5 kg/m² had the highest risk overall, indicating some protective aspects of BMI

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Due to the anonymity of the database, institutional review board approval was deemed unnecessary for this investigation.

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against 30-day medical complications. Thus, obesity alone should not preclude patients from TSA eligibility, rather surgical candidacy should be evaluated in the context of patients' overall health and likelihood of benefit from TSA.

Level of evidence: III, Retrospective Comparative Study.

owing to the increased prevalence of obesity, understanding the influence of high body mass index (BMI) on patients undergoing total shoulder arthroplasty (TSA) is critical. In 2015, 38% of male and 42% of female patients in the United States were reported being obese ($\text{BMI} \geq 30 \text{ kg/m}^2$), with rates projected to rise to 56% for male and 80% for female patients by 2030.¹ Lu et al² studied trends in the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database and found that over 50% of TSA patients were obese or morbidly obese. As a likely consequence of rising indications for TSA and recognition of the effectiveness to treat shoulder pathology, rates of the procedure are also rising, with projection models demonstrating a 235% increase by 2025.³ Given this projected increase in the rate of patients with obesity undergoing TSA, understanding the effect BMI has on TSA is paramount.

While obesity has classically been understood to negatively affect health, recent investigations have found that increased BMI may be contradictorily protective in some cases.⁴⁻⁸ This relationship, coined the “obesity paradox,” was first described in dialysis patients, in which obese and overweight patients had reduced rates of mortality⁹; this trend has been corroborated in patients with cardiovascular disease,⁴ cancer,⁵ and diabetes among other conditions.⁶ This relationship has also recently been identified in the orthopaedic literature. Smith et al⁷ found that total hip arthroplasty patients younger than 60 years with BMI between 35 and 40 kg/m^2 had the lowest medical complication rates. Similar results have been demonstrated in total knee arthroplasty, with BMI between 30 and 35 kg/m^2 being protective of medical complications.⁸ Although mechanisms of this paradox are not certain, some have pointed to the inflammatory and endotoxin protection of lipoproteins.¹⁰ To our knowledge, the obesity paradox has not been studied in the TSA literature. Still, some surgeons designate a BMI limit to reduce their

perceived risk of complications, despite literature reporting otherwise, which may unintentionally reduce access to care in patients who would otherwise not be at an increased risk of a complication.⁷

The purpose of this study was to determine the BMI associated with the lowest rate of medical complications within the first 30 days after TSA. Surgical complications (eg, implant failure or loosening, periprosthetic fracture, or infection), many of which occur outside of 30 days postoperatively, were not assessed. We hypothesized that the obesity paradox also applies to TSA patients and that a nonlinear relationship exists whereby patients with obesity will have a decreased rate of medical complications compared with patients with normal weight and morbid obesity.

Methods

Data Sources and Study Population

The ACS-NSQIP databases from January 1, 2012, to December 31, 2020, were queried for all primary total shoulder arthroplasties. NSQIP systematically samples patients in 706 participating hospitals (in 2020) across the United States and collects data for measuring and improving the quality of surgical care.¹¹ This database is a validated, risk-adjusted, outcome-based program that contains prospectively collected clinical variables on preoperative morbidity, intraoperative variables, and 30-day outcomes for patients undergoing major surgical procedures.¹²

The Current Procedural Terminology code 23472 for TSA was used to identify patients. In the existing classification, Current Procedural Terminology code 23472 includes both anatomic TSA and reverse TSA prostheses. We initially identified 32,280 TSAs with age at surgery >18 and <90 years. We then excluded patients with missing BMI ($n = 168$) and nonelective surgery cases ($n = 150$). A total 31,755 elective TSA procedures were included from 2012 to 2020 to form our study

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population. We retrieved data on demographic characteristics (age, sex, race), current smoking status, and preoperative comorbidities (the American Society of Anesthesia [ASA] physical status classification score, diabetes, history of dyspnea, hypertension, history of CHF (chronic heart failure), history of chronic obstructive pulmonary disease (COPD), dialysis, functional health status, recent weight loss, bleeding disorder, sepsis, and steroid/immunosuppressant use for a chronic condition).

We calculated BMI (kg/m^2) using TSA patients' preoperative height and weight provided in the NSQIP data set. In addition, we classified the BMI value into five categories per the CDC (Centers for Disease Control and Prevention)¹³: underweight (BMI $< 18.5 \text{ kg}/\text{m}^2$), normal weight (BMI ≥ 18.5 and $< 25 \text{ kg}/\text{m}^2$), overweight (BMI ≥ 25 and $< 30 \text{ kg}/\text{m}^2$), obese (BMI ≥ 30 and $< 40 \text{ kg}/\text{m}^2$), and morbidly obese (BMI $\geq 40 \text{ kg}/\text{m}^2$).

Outcomes

The primary outcome of interest was the 30-day risk of postoperative complications. Postoperative complications were defined as any one of the predetermined event as follows: unplanned readmission, any complication, death, superficial incision surgical site infection (SSI), deep incision SSI, organ/space SSI, wound disruption, pneumonia, unplanned intubation, pulmonary embolism, ventilator use greater than 48 hours, progressive renal insufficiency (creatinine rise by more than 2 mg/dL from the preoperative value), acute renal failure (requiring dialysis in the 30-day postoperative window in a patient not previously requiring dialysis), urinary tract infection, stroke/cerebrovascular accident, cardiac arrest requiring cardiopulmonary resuscitation, myocardial infarction, transfusion (intraoperative or postoperative), deep vein thrombosis, sepsis, or septic shock.

Analysis

We conducted all descriptive analyses by operation years (2012 to 2020) because the incidences of any complication decreased with years upon inspection. We summarized demographic characteristics; comorbid conditions; and rates of complications, death, and readmission between operation years. First, bivariable and multivariable logistic regression models (controlling for age, sex, year, and comorbidities) were applied to determine whether BMI categories were associated with a difference in the odds of a complication. To examine the associations between BMI as a continuous variable and risk of any postoperative complication, the available data were split into a training (80%) and test (20%) set. A multi-

variable polynomial logistic regression model was created based on the training data set and subsequently applied to calculate the probability of any complication in the test data set. BMI was modeled as a third-degree polynomial, and the model was adjusted for covariates including age, sex, all preoperative comorbidity variables, and operation year. To visualize the results from our primary analysis, predictive plots of the multivariable polynomial logistic regression model were created to graphically assess the relationship between BMI and the outcome and were further stratified by age (≤ 60 , 61 to 70, 71 to 80, > 80 years) and sex. All statistical analyses were conducted using R Software (version 4.2.0, R Core Team, Vienna, Austria) using $\alpha = 0.05$.

Results

Of the 31,755 elective TSAs included for analysis, most individuals undergoing TSA were White (83.9%), 55.5% were female, and the average age of patients was 69 ± 9 years (range: 19 to 89 years). Approximately 17% of patients were 60 years or older, 36% were 61 to 70 years, 37% were 71 to 80 years, and 10% were younger than 80 years. The preoperative mean BMI was $31 \pm 7 \text{ kg}/\text{m}^2$ (range: 11 to 79); 0.7% were underweight (BMI $< 18.5 \text{ kg}/\text{m}^2$), 16% normal weight (BMI ≥ 18.5 and $< 25 \text{ kg}/\text{m}^2$), 32% overweight (BMI ≥ 25 and $< 30 \text{ kg}/\text{m}^2$), 41% obese (BMI ≥ 30 and $< 40 \text{ kg}/\text{m}^2$), and 11% morbidly obese (BMI $\geq 40 \text{ kg}/\text{m}^2$).

A greater percentage of patients were not current smokers (90%), had an ASA score of ≥ 3 (57%), and were not diabetic (82%). Most of the patients had no history of dyspnea, hypertension requiring medication, CHF history, COPD history, nor dialysis dependence. Most of the patients reported that they were functionally independent, had no recent weight loss, and no history of bleeding disorder, sepsis, or steroid/immunosuppressant use for a chronic condition (Supplementary Table 1, <http://links.lww.com/JAAOS/A950>).

Unplanned readmission occurred for 2.82% ($n = 897$) patients between 2012 and 2020, and the overall rate of any 30-day postoperative complication was 4.53% ($n = 1,440$). Death occurred in 0.14% ($n = 46$) patients. Transfusions (intraoperative and postoperative) were necessary in 2.09% of patients. The rest of the 30-day postoperative complications had an occurrence less than 1% each (Supplementary Table 2, <http://links.lww.com/JAAOS/A951>).

On bivariable logistic regression analysis, overweight and obese patients had a 0.75-times (95% confidence interval [CI], 0.64 to 0.87, $P < 0.001$) and 0.79-times (95% CI, 0.68 to 0.92, $P = 0.002$) lower odds of any postoperative medical complication, respectively, compared with normal-weight patients (Table 1). When adjusting for age, sex, procedure year, and comorbidities, patients with greater than normal BMI demonstrated lower odds of any medical complication compared with normal-weight patients (overweight 0.80 times (95% CI, 0.69 to 0.94, $P = 0.008$), obese 0.81 times (95% CI, 0.69 to 0.94, $P = 0.007$), and morbidly obese patients 0.77 times (95% CI, 0.62 to 0.95, $P = 0.017$)). Thus, bivariable analysis revealed an almost linear relationship of BMI and complication.

Overall, the relationship between BMI and risk of any postoperative complication was nonlinear after adjusting for demographics, all preoperative comorbidity variables, and operation years (Figure 1). Higher BMI was associated with lower risk of postoperative complication until BMI reached 35, after which the curve flattened but remained lower than underweight and normal-weight individuals. We also evaluated and plotted the relationship between BMI and age (in increments of ≤ 60 , 61 to 70, 71 to 80, and > 80) (Figure 2, A). The relationship between age, BMI, and risk of any complication was also nonlinear. While all age groups demonstrated a lower probability of a postoperative complication in the obese BMI range, the probability of a complication increased with increasing age. When evaluating based on sex, the aforementioned trends persisted and female patients demonstrated a higher probability of complications compared with male patients (Figure 2, B).

Discussion

This study of 31,755 elective TSAs in the 2012 to 2020 ACS-NSQIP database is one of the largest to date to evaluate the association between BMI and risk of postoperative medical complications after primary TSA. When adjusting for demographics, preoperative comorbidities, and operation years (2012 to 2020), the relationship between BMI and risk of any postoperative complication was nonlinear and U-shaped. In isolation, a BMI of 30 to 35 kg/m² was associated with the lowest probability of a postoperative medical complication. When stratifying by age and sex, all strata demonstrated a lower probability of complication in the obese BMI range (BMI ≥ 30 and < 40 kg/m²), with older and female patients demonstrating higher probabilities of complications. The ACS-NSQIP database provided similar demographics to what is reported in the shoulder arthroplasty literature,¹⁴ and our findings further highlight the complicated relationship between BMI and surgical risk.

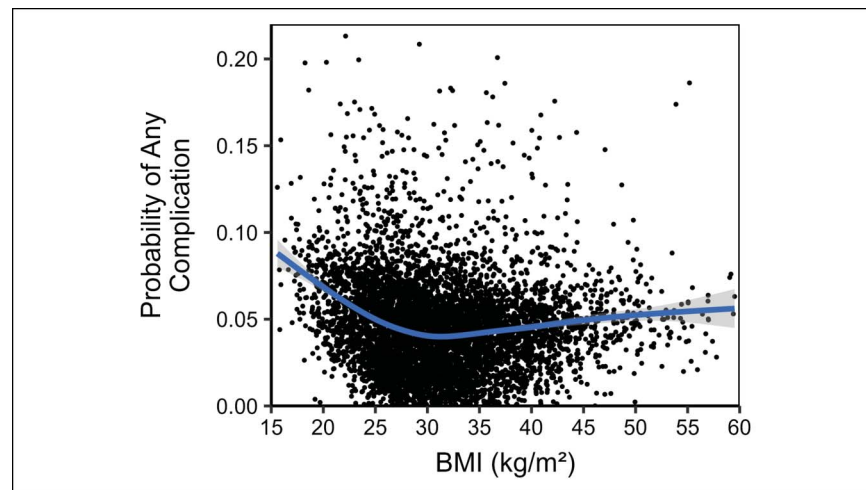
This investigation provides additional analysis into the concept of the obesity paradox⁹ or “reverse epidemiology.”¹⁵ While obesity is generally associated with detrimental health effects, this has been more recently challenged across the literature with studies suggesting that obesity may provide protective qualities in some cases.⁴⁻⁸ The paradoxical BMI and postoperative complication relationship has recently gained interest in orthopaedic literature, especially in lower extremity total joint arthroplasty. Smith et al,⁷ in their evaluation of over 100,000 total hip arthroplasty patients, demonstrated that patients younger than 60 years with a BMI between 35 and 40 kg/m² had lower medical complication rates than underweight and normal-weight individuals. Similarly, Ma et al⁸ showed that

Table 1. Multivariable Logistic Regression Assessing the Effect of Body Mass Index Category on the Risk of Postoperative Medical Complications After Total Shoulder Arthroplasty

BMI Categories	Bivariable OR (95% CI)	P (Walds)	Multivariable OR (95% CI)	P (Walds)
Underweight	1.53 (0.93-2.52)	0.092	1.27 (0.76-2.12)	0.357
Normal weight	Reference	—	Reference	—
Overweight	0.75 (0.64-0.87)	<0.001	0.80 (0.69-0.94)	0.008
Obese	0.79 (0.68-0.92)	0.002	0.81 (0.69-0.94)	0.007
Morbidly obese	0.90 (0.74-1.09)	0.278	0.77 (0.62-0.95)	0.017

BMI = body mass index, CI = confidence interval, OR = odds ratio; TSA = total shoulder arthroplasty
 BMI categories were based on the CDC categories,¹³ defined as underweight (BMI < 18.5 kg/m²), normal weight (BMI ≥ 18.5 and < 25 kg/m²), overweight (BMI ≥ 25 and < 30 kg/m²), obese (BMI ≥ 30 and < 40 kg/m²), and morbidly obese (BMI ≥ 40 kg/m²). Bold indicates statistical significance.

Figure 1



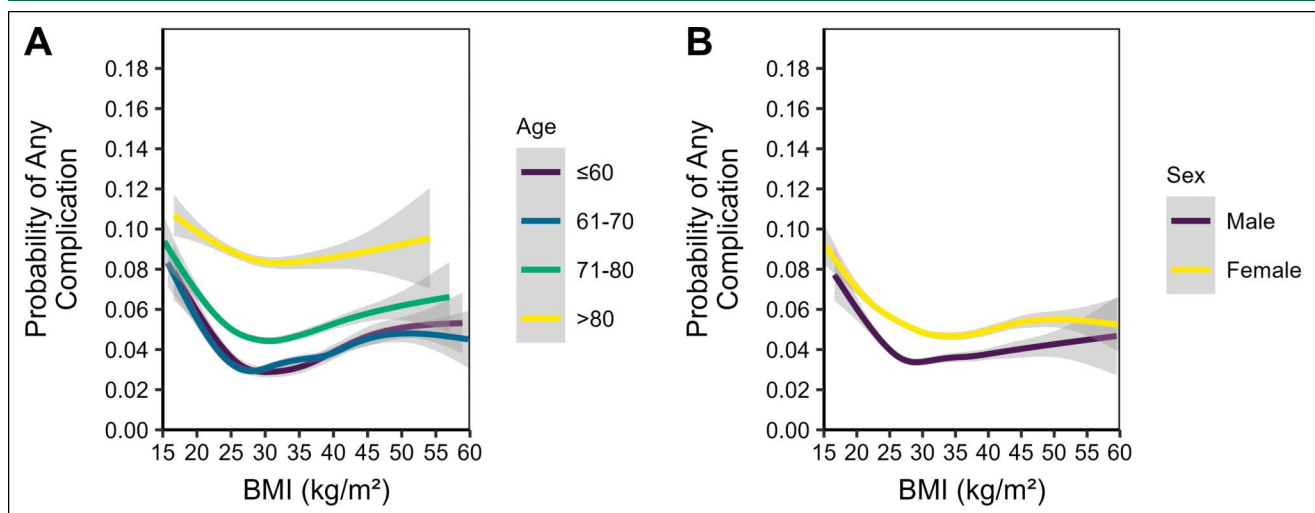
Graph showing a scatterplot of predictive probability of complication risk and body mass index (BMI)

BMI between 30 and 35 kg/m² was protective of medical complications after total knee arthroplasty, in their investigation of nearly 3,000 patients. Our results for postoperative shoulder arthroplasty patients in this BMI range are congruous with these findings, with higher BMI individuals showing lower rates and odds of medical complications. While the clinical picture is becoming clearer, the exact physiologic and pathophysiologic mechanisms correlating BMI and complication risk remain uncertain.

Kalantar-Zadeh et al.¹⁶ discussed several hypotheses for the physiologic etiology of the obesity paradox. One is the endotoxin-lipoprotein hypothesis, which proposes that most individuals with greater weight have higher

concentrations of total cholesterol, which may have protective benefits. Physiologically, it is postulated that larger pools of internal lipoproteins, which can actively bind to and remove circulating endotoxins, protect against deleterious health outcomes such as inflammation and atherosclerosis.¹⁷ The other main hypothesis is the malnutrition-inflammation complex syndrome, which proposes that individuals with obesity have an increase in adipose tissue, and therefore, if they develop a deficiency in energy or protein intake, they would be less likely to become frankly malnourished. Therefore, individuals who are underweight may be more likely to become ill or may recover more slowly compared with individuals with higher BMIs.¹⁸ This is

Figure 2



Graphs of predictive probability of complication risk and body mass index (BMI) (A) stratified by age and (B) stratified by sex

consistent with our findings that underweight individuals (BMI <18.5 kg/m²) actually had the highest postoperative complication rates overall, stratified by age and sex. This may reflect a protective component of BMI, although as BMI increases above overweight, there may be limitations in concluding hard cutoffs for complication risk.

Our results differ from the existing body of evidence defining the relationship between TSA and obesity. Notably, our models found a U-shaped relationship between risk of 30-day postoperative medical complications and BMI. Previous studies investigating the relationship between obesity and medical complications after TSA evaluated BMI in a linear fashion,^{19,20} which our results suggest may not be valid. In addition, prior studies reporting positive clinical outcomes in patients with obesity^{21,22} have also relied on linear models. Although many of these studies included complications past 30 days, our results pertain only to the first 30 days. Furthermore, while our results demonstrate a nonlinear relationship between BMI and risk of postoperative medical complications, this may not apply to TSA complications such as all-cause revision, periprosthetic joint infection, and aseptic loosening. Aggarwal et al²³ determined there was not an increased odds of TSA-related complications in obese patients at 2 and 5 years postoperatively compared with normal-weight or underweight patients on multivariate logistic regression when analyzing patients in a national insurance database.

A limitation of only looking at 30-day complications is that we were not able to evaluate some of these more commonly reported TSA-related complications such as fractures, implant loosening, and cuff tears or cuff failure. Many of these complications exist and become problematic later in the postoperative course, on average for glenoid loosening around 30 months,²⁴ fractures 49 months,²⁵ and cuff problems 15 months.²⁶ BMI may have greater effects outside of the 30-day period evaluated by this database and should be considered. Larger studies should evaluate other longer term complications for the obesity paradox.

We also explored the effects of age and sex on the relationship between BMI and medical complication risk. Similar to prior reports,²⁷ we found that older age at the time of surgery confers a higher risk of 30-day postoperative complications (Figure 2, A). Increased rates of complications in older individuals reported in the literature are likely multifactorial, owing to an increased prevalence of comorbidity as patients age, body composition, and predisposition to complications. Our analysis, which controlled for known comorbidities

unlike much of the literature, found that despite increased age being associated with increased complication risk, BMI between 30 and 35 kg/m² remained protective for older individuals. A limitation of our control is that individuals could have undiagnosed comorbidities. In addition, it is possible that underweight and normal-weight individuals are underdiagnosed with comorbidities more frequently.²⁸ We also found that female patients had a higher risk of postoperative complication than male patients (Figure 2, B). Okoroa et al²⁹ explored the gender influences on shoulder arthroplasty and reported that female patients are at higher risk of certain postoperative complications, which may owe to female patients undergoing shoulder arthroplasty at older ages on average.

In addition, we reviewed overall rates of any medical complications and individual postoperative complication rates both across the study period and by individual year. The postoperative events that were most common were unplanned readmission and transfusion while all other events occurred at a rate less than 1% (Supplementary Table 2, <http://links.lww.com/JAAOS/A951>). Our overall 30-day postoperative complication rate of 4.5% was slightly higher than the 30-day medical complication rate reported previously, but we included a more extensive list of potential medical complications. Villacis et al³⁰ reported an all-cause complication rate of 2.2% for shoulder arthroplasty at 30 days postoperatively and 4.3% at 90 days. Farnig et al³¹ reported a 90-day complication rate of 4.8%. Our readmission rate of 2.8% was in line with the literature, with reports of readmission within 30 days of literature varying between 2.8% and 3.6%.^{32,33} Our reported transfusion rate of 2.1% was lower than much of the reported TSA literature, which ranges from 3.9% to 25%.³⁴⁻³⁶ This may owe to the increasing rates of successful tranexamic acid use in shoulder arthroplasty over the years,^{37,38} as well as differing institutional protocols and potentially improved preoperative assessments.

While this study provides further insight into the relationship between BMI and medical complication risk in TSA patients, there are several limitations. One limitation in the evaluation of postoperative complications is that the ACS-NSQIP database is restricted to a 30-day time frame, limiting any conclusions we can make about longer term complications. Registry studies are also limited by their nonrandomized nature and data being collected across institutions with potential for variability. We also consider the limitation in the use of BMI as the main parameter. BMI does not take into account factors such as body composition, visceral adiposity, sarcopenic

obesity, cardiac fitness, and nutritional status, which are all important health considerations.³⁹ Although we controlled for potential confounders, such as smoking, diabetes, and comorbidities, including cardiac, pulmonary, and renal, this is subject to classification bias. Furthermore, high BMI is associated with metabolic syndrome and corresponding comorbidities associated with poor surgical outcomes⁴⁰; this study is not intended to minimize these facts but rather shed light on the potential pitfalls of BMI as a cutoff. Another limitation of the ACS-NSQIP database is that it is compiled by healthcare entities that have the resources to voluntarily opt-in and contribute data, which may affect the representation of the population in comparison with the rest of the United States. Overall, our population did demonstrate similar population demographics to those reported in the TSA literature.¹⁴ In addition, while our use of multivariable regression controlled for most common confounders associated with the analysis of postoperative medical complications, other potential cofounders may be present.

Conclusion

The relationship between BMI and complication risk in TSA is nonlinear. A BMI between 30 and 35 kg/m² was associated with the lowest risk of medical complications after TSA, and BMI <18.5 kg/m² had the highest risk overall, indicating some protective aspects of BMI against 30-day medical complications. Thus, obesity alone should not preclude patients from TSA eligibility, rather surgical candidacy should be evaluated in the context of patients' overall health and likelihood of benefit from TSA.

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