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Effect of Body Mass Index on Reoperation and Complications After Total Knee Arthroplasty

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Investigation performed at the Mayo Clinic, Rochester, Minnesota

Background: High body mass index (BMI) is associated with increased rates of complications after total knee arthroplasty. To date, to our knowledge, studies have examined risk as a dichotomous variable using specific BMI thresholds. The purpose of this investigation was to quantify implant survival and the risk of common complications after total knee arthroplasty using BMI as a continuous variable.

Methods: Using prospectively collected data from our institutional total joint registry, we analyzed 22,289 consecutive knees, in 16,136 patients, treated with primary total knee arthroplasty from 1985 to 2012. The mean BMI of these patients at the time of the surgical procedure was 31.3 kg/m² (range, 11 to 69 kg/m²). The Kaplan-Meier survival method was used to estimate survivorship, reoperations, and common complications, with associations of outcomes assessed using a Cox regression model.

Results: Utilizing smoothing spline parameterization, we found that reoperation ($p < 0.001$) and implant revision or removal rates ($p < 0.001$) increased with increasing BMI after total knee arthroplasty. Increasing BMI also was associated with increased rates of wound infection (hazard ratio [HR], 1.07; $p < 0.001$) and deep infection (HR, 1.08; $p < 0.001$) per unit of BMI over 35 kg/m². A BMI of 35 to 40 kg/m² was associated with a higher rate of implant revision for aseptic loosening ($p < 0.001$) and for polyethylene wear ($p < 0.001$) compared with a BMI of 18 to 24.99 kg/m². There was no correlation between BMI and risk of venous thromboembolism, tibiofemoral instability, or need for knee manipulation.

Conclusions: The rates of reoperation, implant revision or removal, and many common complications after total knee arthroplasty were strongly associated with BMI.

Level of Evidence: Prognostic Level IV. See Instructions for Authors for a complete description of levels of evidence.

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The effect of obesity on many elective procedures has become an important consideration¹⁻⁶, as it has been estimated⁷⁻⁹ that approximately 35% of adults in the United States and 30% of adults worldwide have a body mass index (BMI) of ≥ 30 kg/m². As the number of obese adults has increased, the costs directly attributed to obesity and associated health-care resource utilization have developed into a necessary concern in elective procedures¹⁰.

Obesity has been identified as an independent risk factor for early development of osteoarthritis of the knee¹¹. It has been estimated¹² that more than one-half of patients undergoing a

total knee arthroplasty have a BMI of ≥ 30 kg/m², many of them at a younger age than their non-obese counterparts^{11,13}. With the demand for total knee arthroplasties projected to increase through 2021¹⁴, it has become even more critical for patients and surgeons to understand the association between BMI and the risk of complications and implant survivorship when making decisions prior to elective procedures.

Morbid obesity has been linked to many early surgical complications after total joint arthroplasty, such as superficial wound infections and thromboembolic events^{12,15-18}. A meta-analysis suggested increased rates of infection requiring a

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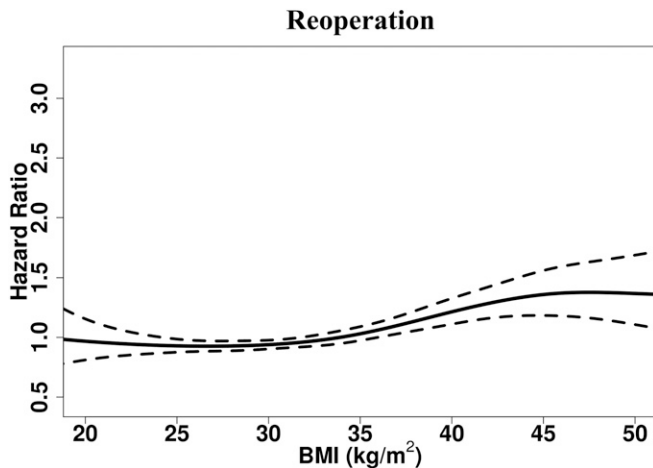


Fig. 1
A graph showing the reoperation risk as a function of BMI. The dashed lines indicate the 95% CI.

revision surgical procedure in obese patients after total knee arthroplasty¹³. Although studies have begun to correlate total knee arthroplasty outcomes with different BMI categories, no previous study, to our knowledge, has comprehensively examined the effects of obesity as a continuous variable across all BMIs.

There also remains controversy regarding the impact of BMI on longer-term implant survivorship and mechanical implant failure. Several studies have not found a significant association, and some have postulated that lower activity levels might offset mechanical effects of increased forces on implants associated with higher BMI^{19,20}. Finally, there is little information on the effect of BMI on the risk of tibiofemoral instability or the need for knee manipulation.

The purpose of this study was to examine the effect of patient BMI on the risk of complications, reoperations, and implant revision or removal after total knee arthroplasty.

Materials and Methods

After institutional review board approval, this investigation was performed utilizing a large, single-institution total joint registry²¹. This registry prospectively captures patient demographic characteristics, operative details, complications, reoperations, implant revisions, and clinical outcome scores for patients treated with total joint arthroplasty. Patients routinely are asked to follow up with the surgeon twice during the year after the operation and then again at postoperative years 2 and 5 and subsequently at 5-year intervals. Patients who are unable to attend follow-up appointments in person are contacted to complete a standardized questionnaire²².

Study Population

Patients who declined research authorization, underwent unicompartmental knee arthroplasty, underwent total knee arthroplasty for tumor resection or acute fracture, or had a prior patellectomy were excluded from the study. All other patients who underwent a primary total knee arthroplasty from January 1, 1985, to December 31, 2012, at our institution were included in this study. Using our total joint registry, we identified patient BMI, demographic characteristics, primary diagnoses, and surgical indications. The study cohort consisted of 22,289 primary total knee arthroplasties (16,136 consecutive patients).

Outcome Measures

The primary outcome measures were reoperation, implant revision or removal for any reason, revision for mechanical failure, aseptic loosening, polyethylene wear or tibiofemoral instability, superficial or deep infection, knee manipulation, and thromboembolic events. Implant survival and risks of reoperation, revision (or implant removal), infection, and knee manipulation were assessed according to BMI.

Statistical Analysis

The Kaplan-Meier survival method was used for survival estimates. Cox proportional hazards regression was used to assess the association of joint arthroplasty outcomes with patient variables. These associations were parameterized using a smoothing spline model. Results are reported as hazard ratios (HRs) with 95% confidence intervals (CIs). Models were adjusted for correlations between the 2 knees in patients who had bilateral primary total knee arthroplasty. The main variable was BMI. We examined each outcome's association with BMI across the range of all BMIs using the smoothing spline graphs. The figures examine HRs as a function of BMI; then the observed patterns (for example, does risk increase at a specific threshold?) on the graphs were used to guide inclusion of BMI thresholds into the models. We examined BMI between 20 and 50 kg/m², setting BMI of <20 kg/m² as equal to 20 kg/m² and BMI of >50 kg/m² as equal to 50 kg/m², because of few patients beyond these extremes. A second analysis was conducted using the commonly used BMI ranges of <18 kg/m², 18 to 24.99 kg/m² (reference group), 25 to 29.99 kg/m², 30 to 34.99 kg/m², 35 to 39.99 kg/m², and ≥40 kg/m². Cumulative risk was calculated by subtracting the 10-year Kaplan-Meier survival rate from 100%. To examine the effects of confounding variables on a possible association of BMI with the outcomes, a multivariate model was

TABLE I Univariate Analysis of Reoperation, Revision or Implant Removal, and Complication Risk Among Total Knee Arthroplasties Stratified by BMI Thresholds

	HR*	P Value
Reoperation		
<30 kg/m ²	1.0	
≥30 kg/m ²	1.03† (1.02 to 1.04)	<0.001‡
Revision or implant removal		
<30 kg/m ²	1.0	
≥30 kg/m ²	1.05† (1.03 to 1.07)	<0.001‡
Infection (superficial and deep)		
<35 kg/m ²	1.0	
≥35 kg/m ²	1.07§ (1.05 to 1.09)	<0.001‡
Infection (deep)		
<35 kg/m ²	1.0	
≥35 kg/m ²	1.08§ (1.05 to 1.11)	<0.001‡
Manipulation under anesthesia		
<30 kg/m ²	1.0	
≥30 kg/m ²	0.96† (0.90 to 1.03)	0.28

*The values are given as the HR, with the 95% CI in parentheses.

†These values are the HR for each 1-unit increase in BMI above 30 kg/m².

‡These values were significant. §These values are the HR for each 1-unit increase in BMI above 35 kg/m².

TABLE II Univariate Analysis of Reoperation, Revision or Implant Removal, and Complication Risk Among Total Knee Arthroplasties Stratified by BMI

	HR*	P Value	Overall P Value	Cumulative 10-Year Risk†
Reoperation			<0.001‡	
<18 kg/m ²	2.79 (1.52 to 5.13)	<0.001‡		20.1% (6.5% to 32.6%)
18 to 24.99 kg/m ²	1.0			10.0% (8.6% to 11.2%)
25 to 29.99 kg/m ²	1.08 (0.93 to 1.26)	0.31		11.2% (10.3% to 12.0%)
30 to 34.99 kg/m ²	1.00 (0.86 to 1.17)	0.99		10.0% (9.1% to 10.9%)
35 to 39.99 kg/m ²	1.34 (1.13 to 1.58)	<0.001‡		13.4% (11.8% to 15.0%)
≥40 kg/m ²	1.46 (1.21 to 1.76)	<0.001‡		14.4% (12.3% to 16.4%)
Revision or implant removal			<0.001‡	
<18 kg/m ²	2.59 (1.15 to 5.82)	0.02‡		7.3% (0.0% to 17.1%)
18 to 24.99 kg/m ²	1.0			5.2% (4.1% to 6.3%)
25 to 29.99 kg/m ²	1.27 (1.03 to 1.56)	0.03‡		6.8% (6.0% to 7.6%)
30 to 34.99 kg/m ²	1.14 (0.92 to 1.42)	0.22		5.7% (5.0% to 6.5%)
35 to 39.99 kg/m ²	1.66 (1.32 to 2.10)	<0.001‡		8.6% (7.1% to 10.0%)
≥40 kg/m ²	1.92 (1.49 to 2.47)	<0.001‡		8.7% (6.9% to 10.5%)
Infection (superficial and deep)			<0.001‡	
<18 kg/m ²	1.94 (0.49 to 7.87)	0.35		2.6% (0.0% to 9.4%)
18 to 24.99 kg/m ²	1.0			2.5% (1.8% to 3.1%)
25 to 29.99 kg/m ²	1.14 (0.84 to 1.54)	0.41		2.8% (2.3% to 3.2%)
30 to 34.99 kg/m ²	1.06 (0.78 to 1.45)	0.70		2.6% (2.2% to 3.1%)
35 to 39.99 kg/m ²	1.35 (0.97 to 1.90)	0.08		3.1% (2.4% to 3.8%)
≥40 kg/m ²	2.09 (1.48 to 2.94)	<0.001‡		5.0% (3.8% to 6.3%)
Infection (deep)			<0.001‡	
<18 kg/m ²	2.67 (0.65 to 10.94)	0.17		2.6% (0.0% to 9.4%)
18 to 24.99 kg/m ²	1.0			1.9% (1.2% to 2.5%)
25 to 29.99 kg/m ²	1.04 (0.72 to 1.50)	0.83		2.0% (1.6% to 2.4%)
30 to 34.99 kg/m ²	0.91 (0.63 to 1.32)	0.62		1.8% (1.4% to 2.1%)
35 to 39.99 kg/m ²	1.25 (0.83 to 1.88)	0.29		2.0% (1.4% to 2.6%)
≥40 kg/m ²	2.01 (1.33 to 3.04)	<0.001‡		3.7% (2.6% to 4.9%)
Manipulation under anesthesia			0.43	
<18 kg/m ²	2.63 (0.58 to 11.84)	0.21		6.2% (0.0% to 16.2%)
18 to 24.99 kg/m ²	1.0			2.6% (1.9% to 3.5%)
25 to 29.99 kg/m ²	1.10 (0.82 to 1.47)	0.52		2.8% (2.4% to 3.4%)
30 to 34.99 kg/m ²	0.97 (0.72 to 1.31)	0.85		2.5% (2.1% to 3.1%)
35 to 39.99 kg/m ²	1.15 (0.82 to 1.61)	0.42		3.0% (2.3% to 4.0%)
≥40 kg/m ²	0.86 (0.57 to 1.30)	0.47		2.2% (1.6% to 3.6%)

*The values are given as the HR, with the 95% CI in parentheses. †The values are given as the 10-year cumulative risk, with the 95% CI in parentheses. ‡These values were significant.

utilized including the variables of age, sex, surgical indication, and time period of the surgical procedure (1985 to 1995, 1996 to 2004, 2005 to 2012). Significance was set at $p < 0.05$.

Results

The mean age at the time of the surgical procedure was 69 years (range, 14 to 96 years), and 56% of patients were female. The mean BMI at the time of arthroplasty was 31.3 kg/m² (range, 11 to 69 kg/m²). There were 12,889 posterior stabilized implants and 9,400 cruciate-retaining designs. Of the total

knee arthroplasties performed, 50 were performed in patients with a BMI of <18 kg/m², 2,800 were performed in patients with a BMI of 18 to 24.99 kg/m², 7,328 were performed in patients with a BMI of 25 to 29.99 kg/m², 6,706 were performed in patients with a BMI of 30 to 34.99 kg/m², 3,277 were performed in patients with a BMI of 35 to 39.99 kg/m², and 2,128 were performed in patients with a BMI of ≥40 kg/m². With regard to the time period of the surgical procedure, the mean BMI in patients who underwent arthroplasty was 29.9 kg/m²

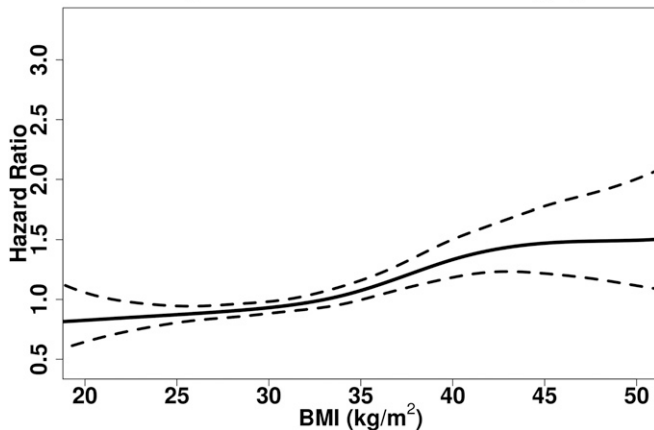
Implant Revision or Removal Surgery

Fig. 2
A graph showing the implant revision or removal risk as a function of BMI. The dashed lines indicate the 95% CI.

from 1985 to 1995, 31.3 kg/m² from 1996 to 2004, and 32.7 kg/m² from 2005 to 2012.

During the period of follow-up, there were 1,233 revision or implant removal surgical procedures, including 623 for mechanical failure, 324 for infection, 150 for tibiofemoral instability, 41 for periprosthetic fracture, and 95 for other reasons. In addition to the revision surgical procedures, 986 additional knees had procedures or reoperations not involving an implant revision surgical procedure: manipulation for limited motion ($n = 461$), superficial infection and wound complications ($n = 275$), and other reasons, including periprosthetic fracture ($n = 250$); 531 knee arthroplasties were followed by thromboembolic events (deep venous thrombosis or pulmonary embolism). For the 6,238 unrevised knee arthroplasties in patients alive at last contact, the mean follow-up after the surgical procedure was 9.5 years (range, 0.1 to 30 years). For the entire cohort of patients who did not undergo revision or implant removal, the mean follow-up was

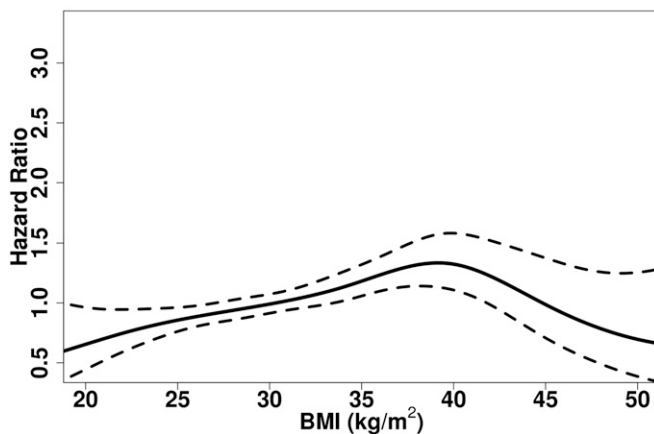
Revision for Mechanical Failure

Fig. 3-A

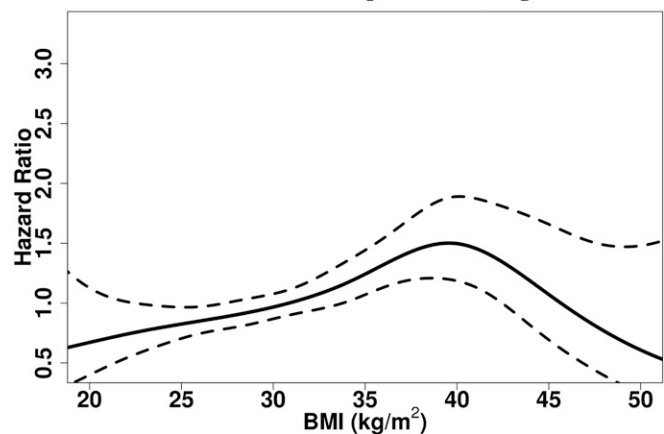
Revision for Aseptic Loosening

Fig. 3-B

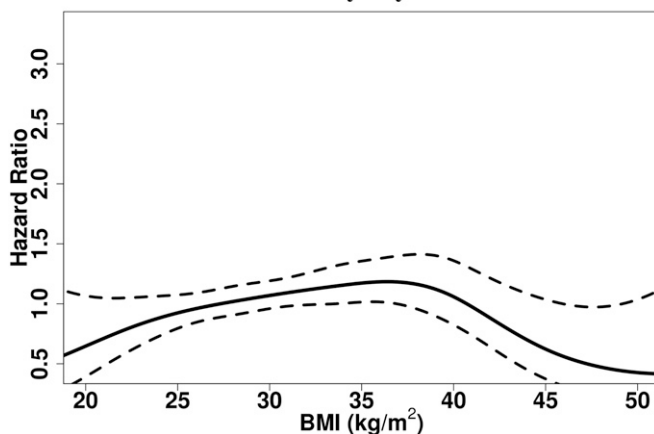
Revision for Polyethylene Wear

Fig. 3-C

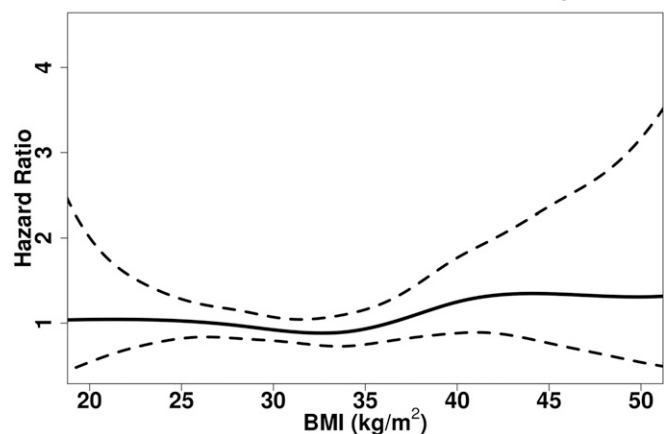
Revision for Tibiofemoral Instability

Fig. 3-D

Figs. 3-A through 3-D Graphs showing the risks of revision surgical procedures for mechanical failure (**Fig. 3-A**), aseptic loosening (**Fig. 3-B**), polyethylene wear (**Fig. 3-C**), and tibiofemoral instability (**Fig. 3-D**) as a function of BMI. The dashed lines indicate the 95% CI.

TABLE III Univariate Analysis of Revision or Implant Removal Risk for Mechanical Failure Among Total Knee Arthroplasties Stratified by BMI

	HR*	P Value	Overall P Value	Cumulative 10-Year Risk†
Any revision for mechanical failure			<0.001‡	
<18 kg/m ²	1.78 (0.49 to 6.47)	0.38		4.8% (0.0% to 13.8%)
18 to 24.99 kg/m ²	1.0			2.0% (1.2% to 2.7%)
25 to 29.99 kg/m ²	1.47 (1.08 to 2.00)	0.01‡		3.8% (3.2% to 4.5%)
30 to 34.99 kg/m ²	1.30 (0.93 to 1.75)	0.13		2.9% (2.3% to 3.5%)
35 to 39.99 kg/m ²	2.24 (1.60 to 3.13)	<0.001‡		5.5% (4.3% to 6.8%)
≥40 kg/m ²	1.49 (0.98 to 2.26)	0.06		3.4% (2.1% to 4.7%)
Aseptic loosening			<0.001‡	
<18 kg/m ²	2.98 (0.81 to 10.97)	0.10		4.8% (0.0% to 13.7%)
18 to 24.99 kg/m ²	1.0			1.4% (0.8% to 2.0%)
25 to 29.99 kg/m ²	1.35 (0.91 to 2.00)	0.14		2.2% (1.8% to 2.7%)
30 to 34.99 kg/m ²	1.26 (0.85 to 1.89)	0.25		1.9% (1.5% to 2.4%)
35 to 39.99 kg/m ²	2.29 (1.50 to 3.49)	<0.001‡		3.5% (2.5% to 6.4%)
≥40 kg/m ²	1.66 (0.99 to 2.77)	0.053		2.5% (1.4% to 3.6%)
Wear			0.001‡	
<18 kg/m ²	0.67 (0.04 to 11.07)	0.78		0.0%
18 to 24.99 kg/m ²	1.0			0.9% (0.4% to 1.5%)
25 to 29.99 kg/m ²	1.47 (1.01 to 2.14)	0.04		2.4% (1.8% to 2.9%)
30 to 34.99 kg/m ²	1.25 (0.85 to 1.84)	0.26		1.6% (1.2% to 2.1%)
35 to 39.99 kg/m ²	2.05 (1.35 to 3.12)	<0.001‡		3.0% (2.0% to 3.9%)
≥40 kg/m ²	0.83 (0.45 to 1.54)	0.56		1.0% (0.2% to 1.8%)
Component fracture			0.15	
<18 kg/m ²	7.88 (0.36 to 170.50)	0.19		0.0%
18 to 24.99 kg/m ²	1.0			0.1% (0.0% to 0.2%)
25 to 29.99 kg/m ²	1.86 (0.54 to 6.38)	0.32		0.3% (0.1% to 0.5%)
30 to 34.99 kg/m ²	1.22 (0.33 to 4.52)	0.76		0.1% (0.0% to 0.3%)
35 to 39.99 kg/m ²	3.47 (0.96 to 12.59)	0.06		0.4% (0.1% to 0.8%)
≥40 kg/m ²	2.95 (0.65 to 13.27)	0.16		0.4% (0.0% to 0.9%)
Revision for tibiofemoral instability			0.29	
<18 kg/m ²	3.01 (0.43 to 21.27)	0.27		6.8% (0.0% to 13.6%)
18 to 24.99 kg/m ²	1.0			1.0% (0.4% to 1.6%)
25 to 29.99 kg/m ²	1.10 (0.65 to 1.88)	0.72		0.6% (0.2% to 1.0%)
30 to 34.99 kg/m ²	0.77 (0.44 to 1.37)	0.38		0.9% (0.6% to 1.2%)
35 to 39.99 kg/m ²	1.21 (0.65 to 2.45)	0.54		0.6% (0.4% to 0.9%)
≥40 kg/m ²	1.41 (0.70 to 2.82)	0.33		0.7% (0.3% to 1.2%)

*The values are given as the HR, with the 95% CI in parentheses. †The values are given as the 10-year cumulative risk, with the 95% CI in parentheses. ‡These values were significant.

11.7 years. The Kaplan-Meier survival estimate free of implant revision or removal was 97% (95% CI, 96% to 97%) at 5 years, 93% (95% CI, 92% to 94%) at 10 years, 88% (95% CI, 87% to 89%) at 15 years, and 82% (95% CI, 81% to 84%) at 20 years.

Reoperation

We found a significant association ($p < 0.001$) between an increased risk of any ipsilateral knee reoperation and increasing BMI (Fig. 1). Beginning at a BMI of 30 kg/m², the smoothing

spline curve demonstrated a 3% increased risk of any reoperation per unit increase in BMI (HR, 1.03; $p < 0.001$) (Table I). When compared with patients with a BMI of 18 to 24.99 kg/m², those with a BMI of 35 to 39.99 kg/m² (HR, 1.34; $p < 0.001$) and those with a BMI of ≥40 kg/m² (HR, 1.46; $p < 0.001$) had an increased risk of reoperation (Table II). The association between reoperation and BMI of 35 to 39.99 kg/m² ($p = 0.04$) and BMI of ≥40 kg/m² ($p = 0.12$) was slightly diminished after taking into account age, sex, surgical indication, and time period (see Appendix).

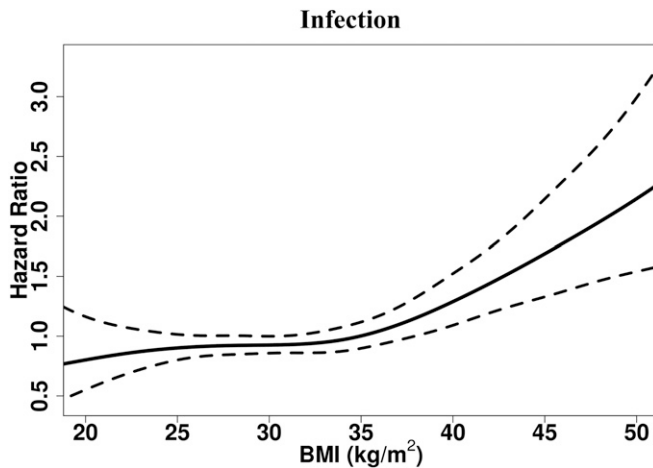


Fig. 4-A

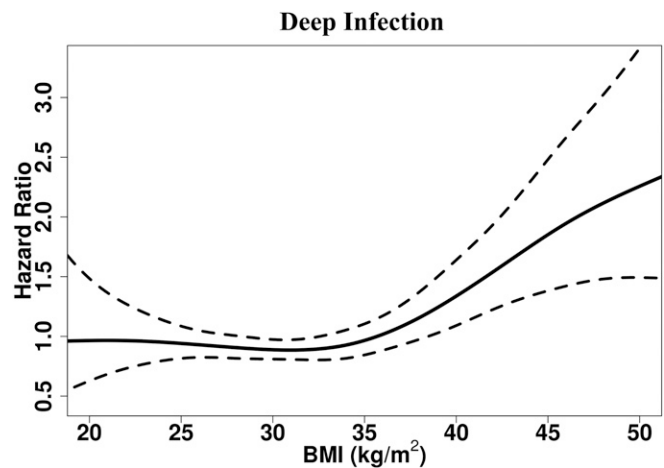


Fig. 4-B

Figs. 4-A and 4-B Graphs showing the risk of superficial and deep infection (**Fig. 4-A**) and of deep infection (**Fig. 4-B**) as a function of BMI. The dashed lines indicate the 95% CI.

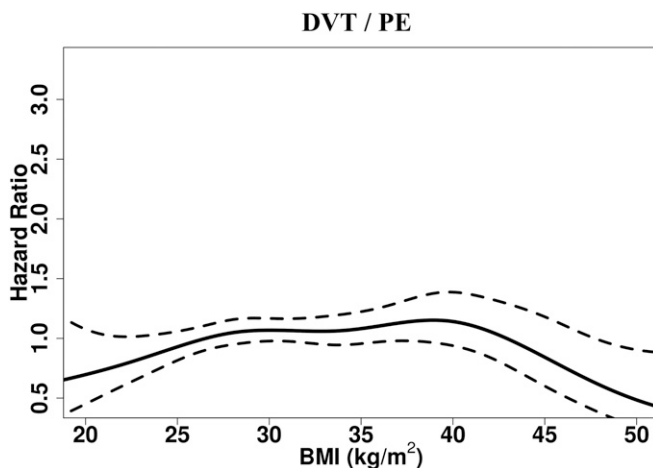


Fig. 5-A

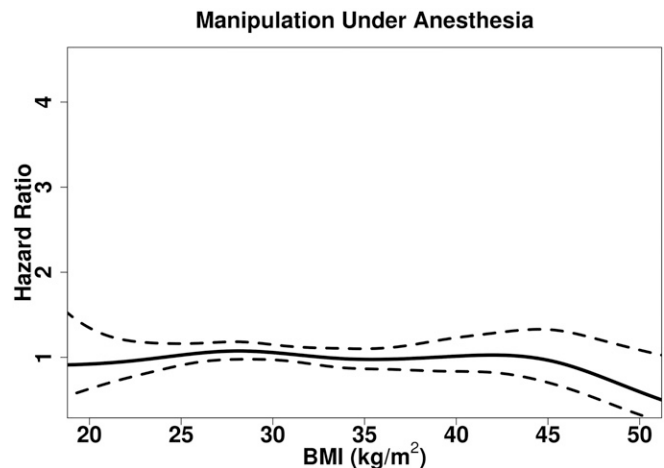


Fig. 5-B

Figs. 5-A and 5-B Graphs showing the risk of thromboembolic events (DVT/PE = deep vein thrombosis or pulmonary embolism) (**Fig. 5-A**) and of manipulation under anesthesia (**Fig. 5-B**) as a function of BMI. The dashed lines indicate the 95% CI.

Implant Revision or Removal

We found a strong association between BMI and the risk of implant revision or removal (Fig. 2). Examining BMI using smoothing spline analysis, there was a 5% increased risk of implant revision or removal for each unit of BMI above 30 kg/m² (HR, 1.05; $p < 0.001$) (Table I). Relative to patients with a BMI of 18 to 24.99 kg/m², there was an increased risk of implant revision or removal for patients with a BMI of 35 to 39.99 kg/m² (HR, 1.66; $p < 0.001$) and those with a BMI of ≥ 40 kg/m² (HR, 1.92; $p < 0.001$) (Table II). The significant association between BMI and revision remained after taking into account age, sex, surgical indication, and time period (see Appendix).

We further evaluated the risk of revision for mechanical implant failure (defined as revision for aseptic loosening, polyethylene wear, or implant fracture) (Fig. 3-A). The risk of revision for mechanical failure overall, aseptic loosening, and

polyethylene wear peaked at a BMI of around 40 kg/m² and then declined for higher BMIs. When compared with patients with a BMI of 18 to 24.99 kg/m², patients with a BMI of 35 to 39.99 kg/m² (HR, 2.24; $p < 0.001$) had a significantly higher risk of revision for mechanical failure, and those with a BMI of ≥ 40 kg/m² (HR, 1.49; $p = 0.06$) also had an increased risk of revision for mechanical failure (Table III). The associations between BMI and revision surgical procedures for mechanical failure remained similar in the multivariate model (see Appendix).

Specific categories of mechanical implant failure also were assessed (Figs. 3-B and 3-C), including risk of revision for aseptic loosening and polyethylene wear. When compared with patients with a BMI of 18 to 24.99 kg/m², there was an increased risk of revision for aseptic loosening in patients with a BMI of 35 to 39.99 kg/m² (HR, 2.29; $p < 0.001$) and borderline-significant increased risk for patients

with a BMI of ≥ 40 kg/m² (HR, 1.66; $p = 0.053$). Compared with patients with a BMI of 18 to 24.99 kg/m², there was an increased risk of revision for polyethylene wear in patients with a BMI of 35 to 39.99 kg/m² (HR, 2.05; $p < 0.001$) but not in patients with a BMI of ≥ 40 kg/m² (Table III). There was no significant association between BMI and the risk of a revision surgical procedure for fractured components among the BMI categories (Table III), although there was a trend toward higher risk in patients with higher BMI for this infrequent complication.

There was no significant association between BMI and risk of revision for tibiofemoral instability (Fig. 3-D).

Infections

A striking association between BMI and complication risk was seen for wound infection (superficial or deep) (Fig. 4-A). The smoothing spline analysis demonstrated that beginning at a BMI threshold of 35 kg/m², there was a 7% increased risk of superficial or deep infection per unit increase in BMI above 35 kg/m² (HR, 1.07; $p < 0.001$) (Table I). Furthermore, patients with a BMI of ≥ 40 kg/m² had more than a twofold increased risk of superficial or deep infection relative to patients with a BMI of 18 to 24.99 kg/m² (HR, 2.09; $p < 0.001$) (Table II). The significant association between a BMI of ≥ 40 kg/m² and infection remained after taking into account age, sex, surgical indication, and time period (see Appendix).

There was also a striking association between BMI and the development of deep periprosthetic infection (Fig. 4-B). Beginning at a BMI of 35 kg/m², there was an 8% increased risk of developing a deep periprosthetic joint infection per unit of BMI (HR, 1.08; $p < 0.001$). Compared with patients with a BMI of 18 to 24.99 kg/m², patients with a BMI of ≥ 40 kg/m² had an increased risk of deep infection (HR, 2.01; $p < 0.001$) (Table II). In the multivariate model, this association between BMI and deep infection remained (see Appendix).

Venous Thromboembolic Events and Risk of Knee Manipulation Under Anesthesia

BMI was not associated with an increased risk of thromboembolic events (Fig. 5-A), nor was it associated with an increased risk of knee manipulation under anesthesia (Fig. 5-B and Tables I and II).

Discussion

In this large consecutive series of 22,289 knees (16,136 patients) treated with total knee arthroplasty, increasing BMI was associated with increasing risk of reoperations, implant revision or removal, and infection. The threshold for BMI at which the risk of complications began to increase was between 30 and 35 kg/m² (depending on the variable), and the increase was progressively more pronounced for higher BMIs and was especially notable in morbidly obese patients (those with a BMI of ≥ 40 kg/m²). BMI was associated with a higher risk of revision for mechanical failure, including aseptic loosening and polyethylene wear, with a peak at a BMI of about 40 kg/m²; however, this risk declined in patients with the highest BMIs.

BMI did not have a significant association with risk of revision for tibiofemoral instability, knee manipulation under anesthesia, and venous thromboembolism.

Periprosthetic Infection

Periprosthetic joint infection was the complication most strongly associated with high BMI. The correlation between infection and obesity has been shown by other authors^{15-17,22-30}, who have reported widely variable levels of risk at different BMI thresholds. There are likely multiple factors that contribute to this finding, including the large adipose tissue layer (large potential dead space that poses an infection risk), comorbidities such as diabetes mellitus (which poses an independent infection risk)^{16,17,26}, and longer operative times (also an independent risk factor for infection)³¹ in patients with higher BMIs. Furthermore, some studies have suggested a proinflammatory state in obese patients, with potentially an impaired immune response to infection³²⁻³⁴.

Revision for Mechanical Failure

Revision for mechanical implant failure etiologies, including aseptic loosening, bearing surface wear, and implant fracture, is one of the most common causes of implant revision in total knee arthroplasty³⁵. There remains a paucity of information linking obesity with mechanical failure after total knee arthroplasty. In fact, although Kerkhoffs et al. demonstrated an increased overall implant revision rate associated with obesity, there were not enough studies in their meta-analysis to support an association between obesity and aseptic implant failure¹³. Our results demonstrate increased rates of mechanical failure for patients with a BMI of 35 to 39.99 kg/m². This increased failure rate was seen for both revision for aseptic loosening and revision for polyethylene wear, with a peak at about a BMI of 40 kg/m² and a decline with a BMI of >40 to 45 kg/m². We hypothesize that the increased stress on implant interfaces and bearing surfaces may account for the higher aseptic loosening and wear rates seen in the patients with a BMI of 35 to 39.99 kg/m². The lack of strongly increased risk of revision for aseptic implant loosening and wear above a BMI of 45 kg/m² may possibly represent lower activity levels in this group of patients^{19,20}.

Comparison with Total Hip Arthroplasty

The results of this study may be compared and contrasted with those of a recent paper using the same methodology on total hip arthroplasty³⁶. As with knee arthroplasty, the risks of reoperation, implant removal or revision, and infection were found to correlate strongly with BMI. However, the risk of infection was even more extreme for patients with a high BMI after total hip arthroplasty than for patients with a high BMI after total knee arthroplasty. For total hip arthroplasty, no correlation was found between BMI and aseptic implant loosening, but such a correlation was demonstrated for patients who had undergone knee arthroplasty, with a peak at a BMI of about 40 kg/m².

Limitations and Strengths

The results of this study should be interpreted in the light of certain limitations. This series consisted of patients treated at a single institution. Although this limited generalizability, it also represented a strength by minimizing potential institutionally based confounders. Also, although the duration of follow-up was limited for some patients, the Kaplan-Meier survivorship analysis accounted for the differences in patient follow-up. We accounted for age, sex, diagnoses, and surgical indications, but we did not account for other patient and surgically related factors, such as the type of implants used. For the complication of infection, high BMI is correlated with risk of diabetes mellitus, which is an independent risk factor for infection, and high BMI also may correlate with other nutritional factors such as serum albumin level that also affect infection risk. Separating the effects of these factors from BMI in individual patients was beyond the scope of this study and represents an area for further study. The frequency of patients with high BMI progressively increased during the time period covered by the study and the practice of knee surgery also changed during the time period of the study. For this reason, the analysis also was performed with a multivariate model including the date of the surgical procedure, which did not dramatically change the results. Finally, significant findings of a small magnitude in large study cohorts may not represent clinically important differences for individual patients.

The major strengths of this study included a large patient population, prospective data collection, and the long period (28 years) of analysis. Furthermore, there was completeness of follow-up for specific end points. Finally, the uniqueness of this study involves the examination of the shape of the curve correlating the effect of BMI over the observed range to each outcome of interest.

Summary

In conclusion, this series contributes to our understanding regarding the association between BMI and the outcomes after total knee arthroplasty, including reoperation, revision, and common complications. These data may be used by patients,

surgeons, and physicians to make informed decisions concerning the relative risks and benefits of elective total knee arthroplasty in patients with different BMIs. Both the provider and the patient may consider the relative risk of a complication as well as the absolute risk of a complication when considering the risks and benefits of an elective procedure. Although the efficacy of preoperative interventions to reduce BMI on preventing complications remains unknown, these findings highlight the potential for collaborative efforts between care providers to reduce complications by modifying preoperative risk factors, such as BMI, prior to elective procedures. In health-care policy and the evolution of different delivery models, these findings may be considered as part of preoperative risk stratification.

Appendix

 Tables showing multivariate analyses among total knee arthroplasties stratified by BMI for reoperation, revision or implant removal, and complication risk and for revision or implant removal risk for mechanical failure are available with the online version of this article as a data supplement at jbjs.org. ■

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