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An increased body mass index was not associated with higher rates of 30-day postoperative complications after unicompartmental knee arthroplasty

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ABSTRACT

Background: The association of postoperative complications and obesity after total knee arthroplasty (TKA) has been well described. However, the effect of an increased body-mass index (BMI) on postoperative complications after unicompartmental knee arthroplasty (UKA) is controversial. Therefore, our aim was to assess the influence of BMI on 30-day postoperative complications after UKA when analyzed as both a categorical and continuous variable.

Methods: The American College of Surgeons National Quality Improvement Program (NSQIP) database was used to identify a total of 8029 patients who underwent UKA from January 1, 2008, to December 31, 2016. The database was queried for over 30 unique complications occurring within 30 days. The impact of BMI on short-term outcomes was assessed as a categorical variable using univariate and multivariate regression. Additionally, BMI was assessed as a continuous variable using spline regressions.

Results: Univariate regression analysis revealed that compared to normal weight patients, overweight patients had a lower risk of major complication (odds ratio [OR], 0.506; 95% confidence interval [CI], 0.279–0.918; $p = 0.025$), and any complication ([OR] 0.632; 95% CI, 0.423–0.944; $p = 0.025$) Multivariate regression analysis found no statistically significant relationship between categorical BMI and complications or outcomes, except for morbidly obese patients who had a greater risk of superficial SSI ($p = 0.026$). Spline regression found no statistically significant non-linear relationships between BMI and any complication ($p = 0.4687$), major complications ($p = 0.1567$), or minor complications ($p = 0.4071$).

Conclusion: Overweight and obese individuals who undergo UKA may not have an increased risk of 30-day postoperative complications compared to normal weight individuals.

1. Introduction

Overall in the United States, more than 40,000 unicompartmental knee arthroplasties (UKA) are performed per year and the growth in utilization has risen at nearly four times the rate of total knee arthroplasty (TKA) [1]. Potential benefits of UKA are the

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reported shorter recovery period compared to TKA, earlier return to physical activity, and potentially superior patient-reported outcomes measures (PROMs) and satisfaction [2–9]. Despite these potential strengths, many surgeons report performing less than five UKA procedures per year and UKA only accounts for eight percent of all the knee arthroplasty surgeries performed in the U.S. per year [1,10]. A recent study that used the Oxford-group selection criteria to assess 200 candidates for either TKA or UKA found that up to 47% of TKA patients are potential candidates for UKA [11]. Therefore, a substantial number of patients who currently are receiving TKAs may be potential candidates for a UKA instead [1,11]. Nonetheless, debate over patient selection remains mainly due to concerns regarding potentially increased rates of revision relative to TKA [11].

Although UKA have been reported to have over 90% 10-year survivorship [12], studies comparing TKA to UKA have generally shown higher rates of revision with UKA [12–14]. Some have suggested that this difference may stem from differences in the threshold to revise a UKA and this notion is supported by data from the United Kingdom that has shown that TKA patients with an Oxford Knee Score below 20 had only a 12% chance of revision versus a 63% chance of revision for similar patients with a UKA [15,16]. In order to minimize the rate of revision and other complications, a set of stringent criteria, including obesity, for selection of UKA candidates have been proposed and subsequent studies have validated successful outcomes when adhering to these indications [17,18]. However, the classic indications for UKA have been revisited with some studies suggesting that certain contraindications do not have an association with short-term complications [19]. More recently the Oxford group has proposed a simplified set of selection criteria that may greatly expand the number of candidates for UKA [12].

Obesity has been associated with higher rates of perioperative complications after TKA, and this may deter providers from offering UKAs to patients despite expansion of classic UKA selection criteria [20–22]. Despite the absence of a correlation between obesity and wear or long-term implant survivorship of UKA, the effect of increased body mass index (BMI) on perioperative complications is still controversial. Furthermore, there is emerging evidence suggesting that overweight and obese patients may have lower rates of short-term complications and superior PROMs with a UKA compared to a TKA [2,23–25]. For example, Lum and colleagues recently undertook a retrospective study comparing a cohort of 650 medial UKA to 1300 TKA in obese patients [2]. This study found similar short-term rates of component revision between the two groups (1.7% in the UKA group versus 1.2% in the TKA group) but substantially fewer deep prosthetic infections, manipulation under anesthesia, or return to operating room in the UKA group [2]. Therefore, the aim of this study was to build on these findings by assessing whether BMI, when analyzed as either a continuous or categorical variable, is associated with higher rates of short-term complications in patients receiving UKA.

2. Methods

2.1. Data source

The American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP), which is a surgical quality improvement program that prospectively collects and reports 30-day morbidity and mortality data, was utilized in the present study. The 2016 version of the database was used, which contains over 250 variables including preoperative risk factors, intraoperative variables, and 30-day postoperative mortality and morbidity outcomes for several major surgical procedures [26]. The database is maintained and updated by trained and certified surgical clinical reviewers. Short-term outcomes in orthopedic surgeries have been extensively evaluated using the NSQIP database [27–29].

2.2. Study population

Patients who underwent UKA from January 1, 2008, to December 31, 2016, were identified using the Current Procedural Terminology (CPT) code 27446, which yielded a total of 8081 patients. Patients were excluded if no BMI was available (n = 35; 0.4%). Additionally, upon sorting the patients into BMI categories, there were 17 (0.2%) patients who were underweight (BMI < 18.5). These patients were excluded from the analysis, as most complication rates in this group were lower than one percent, leaving a total of 8029 cases (99.6%) included in the final analysis. BMI categories were classified according to world health organization (WHO) guidelines: Normal weight = 18.5–24.99 kg/m^2; overweight = BMI 25–29.99 kg/m^2; obese = 30–39.99 kg/m^2; morbidly obese ≥40 kg/m^2 [30].

Of the 8029 eligible cases, 952 (11.9%) of the patients were normal weight, 2550 (31.8%) patients were overweight, 3787 (47.2%) were obese, and 740 (9.2%) patients were morbidly obese. The mean age of the normal weight cohort was 67 ± 12 years (standard deviation), the overweight cohort was 66 ± 10 years, the obese cohort was 63 ± 10 years, and the morbidly obese cohort 58 ± 9 years ($p < 0.001$). Preoperative variables were collected and included patient demographics, comorbidities, and pre-operative lab findings (Table 1).

2.3. Perioperative and postoperative outcomes

Perioperative outcomes of interest included: hospital length of stay (LOS), 30-day return to operating room, LOS longer than 30-days, and home discharge disposition. Specific 30-day complications included: superficial incisional surgical site infection (SSI), deep incisional SSI, organ/space SSI, dehiscence, pneumonia, unplanned intubation, pulmonary embolism, placement on a ventilator greater than 48 h, progressive renal insufficiency, urinary tract infection, stroke or cerebrovascular accident, myocardial infarction, transfusions within 72 h of surgery, deep vein thrombosis requiring therapy, sepsis, septic shock, *Clostridium difficile*

Table 1
Comparison of baseline variables between body mass index (BMI) categories.

Baseline variable	Normal weight N = 952		Overweight N = 2550		Obese N = 3787		Morbidly obese N = 740		p-Value
	n	%	n	%	n	%	n	%	
Female sex	595	62.6	1149	45.1	1940	51.3	510	68.9	<**0.001**
Race									<**0.001**
Other	30	3.2	87	3.4	49	1.3	9	1.2	
Black	22	2.3	57	2.2	157	4.2	51	6.9%	
Unknown	132	13.9	366	14.4	526	13.9	98	13.2	
White	766	80.6	2035	80.0	3050	80.6	582	7.6	
Anesthesia									*0.091*
Other/unknown	148	15.5	391	15.3	563	14.9	112	15.1	
General	415	43.6	1130	44.3	1772	46.8	367	49.6	
Spinal	389	40.9	1029	40.4	1449	38.3	261	35.3	
Diabetes									<**0.001**
Insulin dependent	16	1.7	61	18.3	184	4.9	72	9.7	
Non-diabetic	889	93.4	2280	89.4	3313	82.2	522	70.5	
Non-insulin dependent	47	4.9	209	8.2	490	12.9	146	19.7	
Smoker	89	9.3	239	9.4	384	10.1	89	12.0	*0.170*
Dyspnea									<**0.001**
At rest	1	0.1	3	0.1	8	0.2	1	0.1	
Moderate exertion	24	2.5	83	3.3	194	5.1	50	6.8	
None	927	97.4	2464	96.6	3585	64.7	689	93.1	
Functional status									*0.803*
Independent	934	98.1	2513	98.5	3731	98.5	724	97.8	
Dependent	14	1.5	27	1.1	40	1.1	12	1.6	
Unknown	4	0.4	10	0.4	16	0.4	4	0.5	
History of COPD	18	1.9	59	2.3	121	3.2	31	4.2	**0.007**
History of CHF	0	0.0	4	0.2	5	0.1	1	0.1	*0.823*
Use of hypertension medication	397	41.7	1339	52.5	2360	65.3	486	65.7	<**0.001**
Renal failure	0	0.0	1	0.1	0	0.0	0	0.0	*0.528*
Dialysis	1	0.1	2	0.1	5	0.1	0	0.0	*0.947*
Disseminated cancer	0	0.0	5	0.2	2	0.1	0	0.0	*0.259*
Wound infection	5	0.5	6	0.2	8	0.2	1	0.1	*0.375*
Use of corticosteroids	22	2.3	45	1.8	57	1.5	8	1.1	*0.191*
Weight loss	7	0.7	4	0.2	3	0.1	1	0.1	**0.003**
Bleeding disorder	18	1.9	49	1.9	84	2.2	10	1.4	*0.451*
Previous sepsis	1	0.1	1	< 0.1	5	0.1	1	0.1	*0.536*
Non-clean wound	3	0.3	9	0.4	23	0.6	6	0.8	*0.263*
ASA classification									<**0.001**
1 or 2	702	73.7	1769	69.4	223	58.7	258	34.9	
3 or 4	249	26.2	779	30.6	1562	41.3	482	65.1	
None assigned	1	0.1	1	<0.1	1	<0.1	0	0.0	

	Normal weight N = 952	Overweight N = 2550	Obese N = 3787	Morbidly obese N = 740	p-Value
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Age	67 ± 12	66 ± 10	63 ± 10	58 ± 9	<**0.001**
Operative time	86 ± 34	88 ± 39	88 ± 36	90 ± 33	*0.224*
Sodium	139.2 ± 2.8	139.6 ± 2.6	139.6 ± 2.6	139.7 ± 2.5	<**0.001**
BUN	17.6 ± 6.7	17.9 ± 6.3	17.3 ± 5.9	17.0 ± 7.3	**0.001**
Creatinine	0.9 ± 0.5	0.9 ± 0.3	0.9 ± 0.5	0.9 ± 0.3	**0.026**
White blood cell count	6.5 ± 2.1	6.8 ± 2.0	7.1 ± 2.1	7.7 ± 2.5	<**0.001**
Hematocrit	40.7 ± 3.6	41.7 ± 3.9	41.8 ± 3.8	40.9 ± 4.2	<**0.001**
Platelet count	245.1 ± 63.5	237.2 ± 63.8	239.1 ± 65.1	246.0 ± 66.9	**0.001**

p-Values correspond to Pearson's Chi-square tests, Fisher's exact tests, and one-way analysis of variance (ANOVA) where appropriate, Normal weight = 18.5–24.99 kg/m^2; overweight = BMI 25–29.99 kg/m^2; obese = 30–39.99 kg/m^2; morbidly obese ≥40 kg/m^2. The level of significance for all analysis was set at $p < 0.05$.

infection, 30-day reoperations, 30-day readmissions, 30-day unplanned readmissions, and 30-day mortality, as defined by the ACS NSQIP [26]. Overall 30-day post-operative complications were grouped as: any complication, major complications, and minor complications. Major and minor complications were defined as described in Appendix 1.

2.4. Data analysis

Initially, analysis was performed with BMI treated as a categorical variable. Patient demographics, comorbidities, perioperative outcomes, and 30-day complications between the BMI categories were compared with bivariate analysis. Pearson's Chi-squared tests and Fisher's exact tests were used to compare categorical variables and one-way analysis of variance (ANOVA) was used for continuous variables. Additionally, univariate logistic regression was performed for each complication and outcome for the individual BMI categories using the normal weight category as the reference.

Only baseline variables with a significance of $p \leq 0.01$ were included in the multivariate models to prevent regression over-fitting. Bimodal multivariate logistic regression was used to control for confounding variables and to identify BMI categories as an independent risk factor for each complication. The multivariate logistic regression models included diabetes, Chronic Obstructive Pulmonary Disease (COPD), dyspnea, use of hypertension medication, and weight loss to calculate adjusted odds ratios. These data analyses were performed using International Business Machines Corporation (IBM) Statistical Package for the Social Sciences (SPSS) Statistics 23 for Mac (IBM Corporation, Armonk, NY) and statistical significance was maintained at a p-value of less than 0.05.

The following outcomes of interest were analyzed with BMI as a continuous variable: any complications, major complications, and minor complications. Using BMI, a restricted cubic spline term with four knots in the logistic regression was created to explore the relationship between BMI and the outcomes of interest. To assess whether the relationship between the BMI and the outcomes of interest was nonlinear, Wald statistics were used. To graphically assess the relationships, predictive plots of the spline regression models were created. Odds ratios (the odds of having an outcome at a specified BMI compared to the median BMI) were used in the predictive plots to aid in interpretation. Patients with BMI >60 were not plotted. The level of significance for all analysis was set at $p < 0.05$. Statistical analysis was performed using R software (version 3.1.3, Vienna, Austria). Spline regression analysis was performed using the "rms" package provided with R software [31].

3. Results

Differences between BMI categories were found in several patient demographics and comorbidities including sex, age, race, American Society of Anesthesiologists (ASA) class, diabetes, COPD, use of hypertension medication, and weight loss (Table 1). The incidence of the complications and outcomes among the BMI categories is detailed in Table 2. Univariate regression analysis revealed that compared to normal weight patients, overweight patients had a lower risk of major complication ($p = 0.025$), and any complication ($p = 0.025$). Obese patients had a lower risk of organ/space SSI ($p = 0.029$). Morbidly obese patients had a greater risk of superficial SSI ($p = 0.026$) (Table 3).

Multivariate logistic regression analysis revealed that overweight patients had a lower risk of major complication (odds ratio [OR], 0.488; 95% confidence interval [CI], 0.267–0.892; $p = 0.020$) and any complication (OR, 0.612; 95% CI, 0.407–0.920; $p = 0.018$), obese patients had a lower risk of organ/space SSI (OR, 0.257; 95% CI, 0.071–0.933; $p = 0.039$), while morbidly obese patients had a greater risk of superficial SSI (OR, 3.874; 95% CI, 1.036–14.491; $p = 0.044$) (Table 4) after accounting for potential confounders.

Table 2
Comparison of 30-day complications between body mass index (BMI) categories.

Outcome	Normal weight N = 952		Overweight N = 2550		Obese N = 3787		Morbidly obese N = 740		p-Value[a]
	n	%	n	%	n	%	n	%	
Any complication	39	4.1	67	2.6	129	3.4	29	3.9	*0.087*
Major complication	19	2.0	26	1.0	55	1.5	11	1.5	*0.150*
Minor complication	21	2.2	42	1.6	83	2.0	24	3.2	*0.060*
Superficial SSI	3	0.3	16	0.6	18	0.5	10	1.4	***0.023***
Deep SSI	2	0.2	1	<0.1	7	0.2	4	0.5	***0.033***
Organ/space SSI	5	0.5	7	0.3	5	0.1	1	0.1	*0.112*
Dehiscence	2	0.2	3	0.1	4	0.1	1	0.1	*0.714*
Pneumonia	2	0.2	4	0.2	7	0.2	4	0.5	*0.235*
Reintubation	0	0.0	2	0.1	2	0.1	1	0.1	*0.585*
Pulmonary embolism	3	0.3	5	0.2	10	0.3	2	0.3	*0.863*
Ventilator >48 h	0	<0.1	1	<0.1	2	0.1	1	0.1	*0.631*
Progressive renal insufficiency	0	0.0	1	<0.1	3	0.1	0	0.0	*0.865*
Urinary tract infection	7	0.7	10	0.4	33	0.9	4	0.5	*0.139*
Cerebrovascular accident	0	0.0	0	0.0	3	0.1	0	0.0	*0.539*
Myocardial infarction	2	0.2	1	<0.1	4	0.1	0	0.0	*0.381*
Transfusion	9	0.9	14	0.5	21	0.6	8	1.1	*0.226*
Deep vein thrombosis	3	0.3	8	0.3	19	0.5	3	0.4	*0.725*
Sepsis	1	0.1	5	0.2	7	0.2	2	0.3	*0.872*
Septic shock	0	0.0	1	<0.1	0	<0.1	0	<0.1	*0.528*
C. difficile	0	0.0	0	0.0	2	0.1	0	0.0	*0.694*
Mortality	2	0.3	1	<0.1	1	0.1	0	0.0	*0.166*
Return to OR	12	1.3	28	1.1	39	1.0	15	2.0	*0.135*
Non-home discharge	57	6.8	142	6.3	231	7.0	56	8.6	*0.237*
Still in hospital	0	0.0	1	<0.1	2	0.1	0	0.0	*1.000*
Reoperation	10	1.2	23	1.0	32	1.0	14	2.1	*0.069*
Readmission	28	3.4	61	2.7	78	2.4	20	3.1	*0.361*
Unplanned readmission (% of readmissions)	25	83.3	58	90.6	71	86.6	18	18.8	*0.583*

Normal weight = 18.5–24.99 kg/m^2; overweight = BMI 25–29.99 kg/m^2; obese = 30–39.99 kg/m^2; morbidly obese ≥40 kg/m^2.

[a] p-Values correspond to Pearson's Chi-square tests and Fisher's exact tests where appropriate.

Table 3
Comparison of 30-day complications between body mass index (BMI) categories, having normal weight as reference.

Outcome	Overweight vs. normal weight			Obese vs. normal weight			Morbidly obese vs. normal weight		
	Odds ratio	95% CI	p-Value	Odds ratio	95% CI	p-Value	Odds ratio	95% CI	p-Value
Any complication	0.632	(0.423–0.944)	***0.025***	0.826	(0.573–1.190)	*0.304*	0.955	(0.565–1.559)	*0.854*
Major complication	0.506	(0.279–0.918)	***0.025***	0.724	(0.427–1.225)	*0.229*	0.741	(0.350–1.567)	*0.433*
Minor complication	0.742	(0.437–1.260)	*0.270*	0.993	(0.612–1.612)	*0.979*	1.486	(0.821–2.691)	*0.191*
Superficial SSI	1.997	(0.581–6.870)	*0.272*	1.511	(0.444–5.139)	*0.509*	4.333	(1.188–15.802)	***0.026***
Deep SSI	0.186	(0.017–2.057)	*0.170*	0.880	(0.182–4.241)	*0.873*	2.582	(0.472–14.133)	*0.274*
Organ/space SSI	0.521	(0.165–1.647)	*0.267*	0.250	(0.072–0.867)	***0.029***	0.256	(0.030–2.198)	*0.214*
Dehiscence	0.559	(0.093–3.353)	*0.525*	0.502	(0.092–2.746)	*0.427*	0.643	(0.058–7.102)	*0.718*
Pneumonia	0.746	(0.130–4.081)	*0.736*	0.880	(0.182–4.241)	*0.873*	2.582	(0.472–14.133)	*0.274*
Reintubation	1.268×10^6	(0.000-)	*0.991*	8.536×10^5	(0.000-)	*0.992*	2.186×10^5	(0.000-)	*0.991*
Pulmonary embolism	0.621	(0.148–2.606)	*0.515*	0.838	(0.230–3.049)	*0.788*	0.857	(0.143–5.144)	*0.866*
Ventilator >48 h	6.338×10^5	(0.000-)	*0.992*	8.536×10^5	(0.000-)	*0.992*	2.186×10^6	(0.000-)	*0.991*
Progressive renal insufficiency	6.338×10^5	(0.000-)	*0.992*	1.281×10^6	(0.000-)	*0.991*	1.000	(0.000-)	*1.000*
Urinary tract infection	0.531	(0.202–1.400)	*0.201*	1.187	(0.523–2.691)	*0.682*	0.734	(0.214–2.516)	*0.622*
Cerebrovascular accident	1.000	(0.000-)	*1.000*	1.281×10^6	(0.000-)	*0.991*	1.000	(0.000-)	*1.000*
Myocardial infarction	0.186	(0.017–2.057)	*0.170*	0.502	(0.092–2.746)	*0.427*	0.000	(0.000-)	*0.992*
Transfusion	0.578	(0.250–1.341)	*0.202*	0.584	(0.267–1.280)	*0.179*	1.145	(0.440–2.982)	*0.781*
Deep vein thrombosis	0.996	(0.264–3.760)	*0.990*	1.595	(0.471–5.401)	*0.453*	1.288	(0.259–6.398)	*0.757*
Sepsis	1.868	(0.218–16.013)	*0.569*	1.761	(0.216–14.331)	*0.597*	2.577	(0.233–28.477)	*0.440*
Septic shock	6.337×10^5	(0.000-)	*0.992*	1.000	(0.000-)	*1.000*	1.000	(0.000-)	*1.000*
C. difficile	1.000	(0.000-)	*1.000*	2.340×10^6	(0.000-)	*0.995*	1.000	(0.000-)	*1.000*
Mortality	0.186	(0.017–2.057)	*0.992*	0.125	(0.011–1.385)	*0.090*	0.000	(0.000-)	*0.992*
Return to OR	0.870	(0.440–1.717)	*0.688*	0.815	(0.425–1.563)	*0.538*	1.621	(0.754–3.484)	*0.216*
Non-home discharge	0.925	(0.673–1.271)	*0.631*	1.032	(0.764–1.393)	*0.839*	1.294	(0.882–1.899)	*0.188*
Still in hospital	7.827×10^5	(0.000-)	*0.993*	1.059×10^6	(0.000-)	*0.992*	1.000	(0.000-)	*1.000*
Reoperation	0.857	(0.406–1.809)	*0.686*	0.810	(0.397–1.655)	*0.564*	1.816	(0.801–4.114)	*0.153*
Readmission	0.808	(0.513–1.273)	*0.357*	0.696	(0.449–1.080)	*0.106*	0.919	(0.513–1.646)	*0.776*
Unplanned readmission	1.933	(0.540–6.926)	*0.311*	1.291	(0.408–4.802)	*0.644*	0.900	(0.212–3.828)	*0.900*

The level of significance for all analysis was set at $p < 0.05$.

Spline regression found no statistically significant non-linear relationships between BMI and any complication ($p = 0.4687$), major complications ($p = 0.1567$), or minor complications ($p = 0.4071$) after accounting for potential confounders (Figure 1).

Table 4
Multivariate logistic regression analyses.

Outcome	Overweight vs. normal weight			Obese vs. normal weight			Morbidly obese vs. normal weight		
	Odds ratio	95% CI	p-Value	Odds ratio	95% CI	p-Value	Odds ratio	95% CI	p-Value
Any complication	0.612	(0.407–0.920)	***0.018***	0.745	(0.513–1.082)	*0.122*	0.73	(0.441–1.207)	*0.220*
Major complication	0.488	(0.267–0.892)	***0.020***	0.657	(0.383–1.126)	*0.127*	0.621	(0.287–1.341)	*0.225*
Minor complication	0.721	(0.422–1.234)	*0.233*	0.883	(0.540–1.446)	*0.622*	1.069	(0.581–1.965)	*0.831*
Superficial SSI	1.942	(0.561–6.727)	*0.295*	1.475	(0.428–5.078)	*0.538*	3.874	(1.036–14.491)	***0.044***
Deep SSI	0.182	(0.016–2.029)	*0.166*	0.891	(0.180–4.402)	*0.888*	2.586	(0.442–15.188)	*0.292*
Organ/space SSI	0.537	(0.163–1.775)	*0.308*	0.257	(0.071–0.933)	***0.039***	0.261	(0.029–2.372)	*0.233*
Dehiscence	0.434	(0.071–2.659)	*0.367*	0.306	(0.054–1.726)	*0.180*	0.340	(0.030–3.926)	*0.388*
Pneumonia	0.663	(0.199–3.698)	*0.640*	0.587	(0.117–2.941)	*0.517*	1.380	(0.240–7.925)	*1.380*
Reintubation	1.047×10^6	(0.000-)	*0.991*	5.306×10^5	(0.000-)	*0.991*	9.429×10^5	(0.000-)	*0.991*
Pulmonary embolism	0.616	(0.145–2.611)	*0.511*	0.819	(0.220–3.050)	*0.766*	0.785	(0.125–4.941)	*0.797*
Ventilator >48 h	5.807×10^5	(0.000-)	*0.991*	6.091×10^5	(0.000-)	*0.991*	9.905×10^5	(0.000-)	*0.991*
Progressive renal insufficiency	3.456×10^5	(0.000-)	*0.991*	8.041×10^5	(0.000-)	*0.990*	1.186	(0.000-)	*1.000*
Urinary tract infection	0.543	(0.205–1.441)	*0.220*	1.085	(0.472–2.493)	*0.847*	0.561	(0.160–1.967)	*0.366*
Cerebrovascular accident	1.641	(0.000-)	*1.000*	1.532×10^6	(0.000-)	*0.990*	1.162	(0.000-)	*1.000*
Myocardial infarction	0.112	(0.010–1.273)	*0.078*	0.236	(0.040–1.397)	*0.111*	0.000	(0.000-)	*0.991*
Transfusion	0.562	(0.239–1.339)	*0.195*	0.520	(0.234–1.158)	*0.110*	0.719	(0.268–1.929)	*0.513*
Deep vein thrombosis	1.038	(0.273–3.949)	*0.957*	1.624	(0.473–5.573)	*0.441*	1.265	(0.247–6.478)	*0.778*
Sepsis	1.779	(0.205–15.440)	*0.601*	1.342	(0.161–11.199)	*0.786*	1.696	(0.145–19.895)	*0.674*
Septic shock	5.322×10^5	(0.000-)	*0.990*	1.050	(0.000-)	*1.000*	1.362	(0.000-)	*1.000*
C. difficile	0.938	(0.000-)	*1.000*	8.852×10^5	(0.000-)	*0.993*	0.380	(0.000-)	*1.000*
Mortality	3.981×10^4	(0.000-)	*0.991*	6.389×10^5	(0.000-)	*0.992*	3.341×10^5	(0.000-)	*0.992*
Return to OR	0.871	(0.427–1.775)	*0.704*	0.771	(0.387–1.535)	*0.459*	1.366	(0.609–3.066)	*0.450*
Non-home discharge	0.955	(0.690–1.322)	*0.783*	0.903	(0.663–1.231)	*0.520*	0.844	(0.568–1.254)	*0.400*
Still in hospital	7.362×10^5	(0.000-)	*0.992*	1.155×10^6	(0.000-)	*0.992*	1.343	(0.000-)	*1.000*
Reoperation	0.848	(0.388–1.852)	*0.679*	0.743	(0.349–1.580)	*0.441*	1.443	(0.607–3.432)	*0.406*
Readmission	0.715	(0.451–1.132)	*0.153*	0.569	(0.364–0.891)	*0.014*	0.698	(0.383–1.270)	*0.238*
Unplanned readmission	1.954	(0.505–7.563)	*0.332*	0.766	(0.218–2.701)	*0.679*	0.403	(0.069–2.372)	*0.315*

The level of significance for all analysis was set at $p < 0.05$.

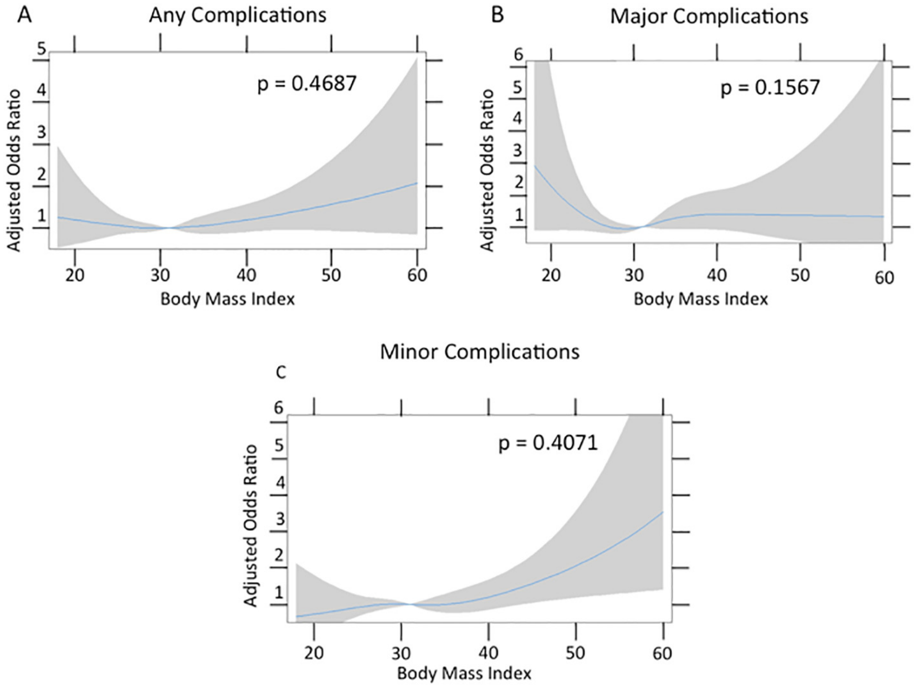

Figure 1. Predictive plots of spline regression models showing the relationship among BMI and (A) adjusted odds ratio of any complication; (B) adjusted odds ratio of major complications; and (C) adjusted odds ratio of minor complications. No statistically significant non-linear relationships between BMI and any complication ($p = 0.4687$), major complications ($p = 0.1567$), or minor complications ($p = 0.4071$) after accounting for potential confounders were found.

4. Discussion

Obesity is a sizeable health problem which affects over 30% of the United States population. Over 50% of the 8029 Unicompartimental knee replacement (UKR) patients studied in this cohort were obese or morbidly obese. This replicates prior findings in the TKA literature of the United States that have found rates of obesity and morbid obesity ranging between 62.3% (American NSQIP cohort) [29] and 70% (American National Inpatient Sample (NIS) database in 2011) [33]. Other studies of UKA have also noted high rates of obesity among patients undergoing the procedure. A single-institution database in the United States reported an average BMI of 29.24 (standard deviation 4.82) kg/m^2 [34]. Similarly, a large database of over 40,000 UKA patients in the United Kingdom reported BMI of 29.9 (standard deviation five) [35] Assuming that the population mean of cases is normally distributed, in these prior studies 50% of more of the patients undergoing UKA would probably be either obese or morbidly obese. The reasons for this finding are unclear. However, this could be due to the association between obesity and symptomatic osteoarthritis. Multiple studies have shown an association between complications and obesity in TKA patients, and health providers may extrapolate these findings and expect similar perioperative complications in UKA performed in patients with increased BMI [20–22,29,36–39]. However, in this study employing a large national database, we have not found an association between a higher BMI and a higher rate of short-term complications following UKA.

While this study holds the strength of a large sample size clinical registry, diversity of the patient population, and the assessment of diverse outcome measures, it has limitations. Despite the proven reliability of the data [40], and the robust statistical analyses, the NSQIP database only includes outcomes up to 30 days after surgery and longer follow-up information was not available. Furthermore, intrinsic limitations to the study design utilizing this database are that actual patient records are not accessible and the data assessed is predefined, and financial and geographical analyses are not available. Therefore the findings of this study will need to be correlated to long term survivorship data, clinical outcomes and patient satisfaction [41,42]. Notwithstanding these limitations, this is one of the largest studies to date to analyze the effect of BMI on complications after UKA.

Despite obesity being listed as a classic contraindication to performing a UKA [43], the indication criteria for UKA are still controversial and vary widely. Over the few past years, claims have been made that obesity may not serve as an accurate contraindication for the procedure when delivered in a specialty musculoskeletal health hospital [19,44]. Supporting this statement and the findings of our study, a retrospective study of 650 UKAs versus 1300 TKAs, with a BMI >35 kg/m^2, showed that obese patients receiving a UKA had similar or slightly lower rates of complications than those undergoing TKA [2]. Specifically they reported lower rates of superficial and deep infection ($p = 0.016$), short length of hospital stay, lower rates of manipulation under anesthesia ($p < 0.001$) and similar survivorship and component revision in obese patients receiving a UKA compared to TKA. Furthermore, severely obese patients had improved Knee Society Function scores and maintenance of range of motion after UKA compared with TKA. Therefore the findings of our study, support the findings from Lum et al. [2] which challenges the classic contraindication of obesity as a selection criterion for UKA, and warrants further investigation. The reasons explaining why morbidly obese and obese patients undergoing UKA did not have greater risk of 30-day complications are not entirely clear. However this could be related to a phenomenon previously described as the *obesity paradox*. This paradoxical decrease in morbidity with increasing BMI has been shown in patients with heart failure undergoing percutaneous coronary intervention. The proposed mechanism is that these patients have a more robust physiologic reserve that "protects" them from complications, or possibly they are just managed more aggressively post-operatively. To note this effect has not been well-described in the orthopedic surgery literature [46].

Contrariwise, Kandil et al. conducted a large database study using the PearlDiver™ data set, with over 15,000 UKA patients and found a dose-dependent effect of obesity on both short-term complications and revision within two years of surgery [23]. Despite this study's strengths, it draws conclusions from a univariate analysis, which is a limitation of the PearlDiver™ database (claims-based data), which reports data in groups since individual patient cannot easily be tracked, limiting linkage and comparative studies of procedures and/or complications. Similarly, Haughom et al. conducted a study on risk factors for complications and prolonged length of stay after UKA utilizing the NSQIP database (2005–2012) analyzing 2300 UKAs [47]. They identified obesity and COPD as risk factors for length of stay greater than four days and any complication. Kort et al. found in a prospective trial of 43 obese and non-obese patients that obesity may pose increased technical difficulty [48], however differences in the rate of complications between the two groups did not reach statistical significance.

Furthermore, beyond the effect on short-term complications, the effect of obesity on long term UKA survivorship is of utmost importance. Overall, several studies have concluded that obesity did not affect the survivorship or revision rate after UKA. Plate et al. found that BMI did not influence rates of revision in a study of over 700 UKA patients with the examined robotic assisted UKAs using Stryker Makoplasty™ (Stryker Corporation, Kalamazoo, Michigan, United States), but they did note that BMI correlated with higher opiate utilization and number of physical therapy visits needed to achieve discharge goals [25]. Taboor et al. conducted a longitudinal study of 100 UKAs and found that obese patients who underwent UKA actually had better survivorship than non-obese patients at 20 years [49]. Two studies evaluating groups categorized according to BMI found no differences in survival rate between groups: Murray et al. analyzed over 2400 cases of medial Oxford UKRs [50] and Cavaignac et al. analyzed a cohort of 212 patients and found no statistically significance between obese (92.5% survival) and non-obese (93.5% survival) in a 10-year Kaplan–Meier survival analysis [51]. A single-center, single surgeon case series of 159 UKA patients, including 17.4% lateral UKAs, similarly found that BMI did not influence revision rate [52]. Kuipers et al. found a similar result in a multi-surgeon, multi-center retrospective study in the United Kingdom in which they found that neither obesity nor patella-femoral disease was associated with decreased survivorship after UKA [53]. Zengerink and colleagues found an 87% survival rate at five years and found no significant difference between obese and non-obese patients [54]. Woo et al. reported a five-year revision rate of 1.3% among over 600 severely obese patients treated at their center, [24] and their multivariate analysis found no association between BMI and early failure or poor post-operative functional status.

On the other hand, several studies have reported a trend toward increased rates of revision among patients with higher BMI that did not reach statistical significance. For example, Saenz et al. conducted a retrospective cohort study of 144 patients and found a trend toward increased rates of revision among obese patients; however, multi-regression analysis found that this relationship was not statistically significant [55]. Smaller studies with both prospective and retrospective design have shown similar findings. Cepni et al. reported a cohort study of 67 obese patients over the age of 60 and found no signs of prosthesis failure or lateral compartment arthritis, although there were three cases of insert dislocation in obese patients receiving a phase 3 mobile bearing Oxford knee™ [56]. Seyler et al. conducted a similar study with a comparison group of non-obese patients and found that obese patients ($n = 40$) had a 12.5% risk of revision within five years versus non-obese patients ($n = 40$) who had no complications, though this trend did not reach statistical significance when analyzed with a Cox proportional hazard model [57]. Naal et al. found that after two years, BMI had no correlation with increased rates of revision; however, they did find a correlation between BMI and higher incidence of anterior knee pain [58].

5. Conclusion

Overweight and obese individuals who undergo UKA may not have an increased risk of 30-day postoperative complications compared to normal weight individuals. Only morbidly obese patients had a greater risk of superficial skin infection after UKA.

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Declaration of interest

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American Association of Hip and Knee Surgeons: Board or committee member
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CD Diagnostics: Research support
Cempra: Research support

Cymedica: Research support
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Journal of Hip Surgery: Editorial or governing board
Journal of Knee Surgery: Editorial or governing board
KCI: Paid consultant; Paid presenter or speaker; Research support
Mid-American Orthopaedic Association: Board or committee member
Musculoskeletal Infection Society: Board or committee member
OREF: Research support
Orthofix, Inc.: Research support
Pfizer: Paid consultant
PSI: Stock or stock Options
Stryker: Research support
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Appendix A. Supplementary data

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