Effect of body mass index on postoperative mechanical alignment and long-term outcomes after total knee arthroplasty: a retrospective cohort study of 671 knees

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Background: A high body mass index (BMI) is associated with increased rates of complications after total knee arthroplasty (TKA). However, no study has examined the effect of BMI on lower limb alignment using the World Health Organization's (WHO) BMI classification. We believe that the WHO's BMI classification allows a uniform standard worldwide. We sought to investigate the potential association between a high BMI and the incidence of postoperative misalignment. We also evaluated whether a higher BMI is associated with worse clinical function.

Methods: We retrospectively reviewed the data of 671 patients who underwent primary TKA for varus osteoarthritis between January 2010 and December 2015. The patients were divided into the following 5 groups based on their BMI: normal weight (<25.0 kg/m^2), overweight (25.0–29.9 kg/m^2), class I obese (30.0–34.9 kg/m^2), class II obese (35–39.9 kg/m^2), and class III obese (>40 kg/m^2). Both weight and height were measured by nurses on admission. Patients' preoperative HKA, gender, age, and side of surgery were collected as baseline. All the patients underwent standing, weight-bearing, full-length radiography before and after surgery to measure the mechanical hip-knee-ankle angle (HKA). We followed up patients by telephone. Among the BMI subgroups, we compared the knee function scores, including the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score, Knee Society-Knee Score (KS-KS), Knee Society-Function Score (KS-FS), Forgotten Joint Score (FJS), and range of motion (ROM). A multivariate linear regression analysis and a logistic regression was conducted to examine the outcomes.

Results: The study had a mean follow-up period of 8.16 years. The multivariate and logistic regression analyses revealed that preoperative alignment (P=0.002) and a higher BMI (P=0.015) were associated with a higher risk of postoperative misalignment. The WOMAC scores were higher in the normal and overweight groups than the other groups (P=0.022). The FJS and KS-KS gradually decreased as BMI increased.

Conclusions: A higher BMI is associated with a greater risk of misalignment and worse long-term clinical outcome after TKA. When treating patients with high BMI, we should pay more attention to the adjustment of lower limb alignment intraoperatively.

Keywords: Total knee arthroplasty (TKA); obesity; body mass index (BMI); varus knee; alignment

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Introduction

The increase in the prevalence of obesity since the early 1980s represents a significant health burden worldwide (1). Obesity contributes to a higher risk of osteoarthritis and ultimately, to an increased demand for total knee arthroplasty (TKA) (2). It has been predicted that the demand for primary TKA will reach nearly 3.5 million cases by the year 2030 (3). Given the increasing prevalence of obesity and the demand for TKA, there will be an inevitable increase in the proportion of TKA patients who are obese.

Knee alignment within 3° of neutrality has historically been defined as "neutral alignment" and considered "safe" (4). Misalignment beyond this "safe zone" may increase the load on the prosthetic implant, which in turn may increase the amount of wear (5). Obesity has been associated with the suboptimal overall mechanical alignment of knee components (6,7). A high body mass index (BMI) increases the stress on the underlying bone and implant material, which adversely affects prosthetic longevity and functional gain (8).

The direct and indirect effects of obesity imply that patients with a higher BMI should have worse postoperative alignment after TKA, resulting in worse long-term function and lower prosthesis survival rates (6,9). However, there is no definitive BMI cutoff that accurately separates high-risk patients from low-risk patients. The threshold of 30 kg/m^2 remains controversial, and studies in which patients were categorized using BMI cutoff values of 35 and 40 kg/m^2 were able to identify more differences in overall complication rates or implant survival (10,11). We believe that because the authors aimed to magnify the gap in post TKA outcomes between obese and nonobese, the cut-off was set at 35 or 40 kg/m^2. But this may make the results too idealized to have an instructive role in clinical work. Previous studies (7,12-14) investigating the relationship between obesity and poor postoperative alignment after TKA have yielded conflicting results. However, these studies stratified patients using a BMI threshold of 35 kg/m^2, which does not reflect the World Health Organization's (WHO's) recommendations.

Conversely, a prospective, matched case-control study (12) found no difference in the overall alignment of components between morbidly obese patients (BMI >40 kg/m^2) and non-obese patients (BMI <30 kg/m^2), but that study did not specify whether full-length hip-ankle radiography was performed, nor did it report the incidence of misalignment. Similarly, another study (14) reported no difference in the alignment of femoral or tibial components in the coronal or sagittal plane between obese patients (BMI ≥30 kg/m^2) and non-obese (BMI <30 kg/m^2), but again that study did not report quantitative data on misalignment. Another study (15) reported no difference in the mean tibial coronal alignment between obese and non-obese patients when an extramedullary guide was used during primary TKA.

The discrepancy among these studies may at least partly be due to the use of short knee radiography, small samples, and other methodological problems. Only 2 studies (6,15) have used standing, full-length, hip-to-ankle radiography to measure HKA, which is thought to provide accurate information on limb alignment and component alignment with respect to the weight-bearing mechanical axis (6,16). Additionally, studies on the relationship between BMI and TKA have now largely focused on the incidence of postoperative infection and prosthetic survival times but have ignored the effect of BMI on joint function.

The relationship between BMI and the percentage of body fat is age and sex dependent and varies among racial groups (17). Differences in BMI cutoffs may occur across ethnicities. The WHO standards for BMI classification of Chinese population are as follows: normal (18.5–23.9 kg/m^2), overweight (24–27.9 kg/m^2), obesity (≥28 kg/m^2). However, ethnic-specific cut-off points for BMI were thought to increase confusion in health promotion, and disease prevention and management in the increasingly multicultural societies (18). We believe that adoption of the WHO uniform international standards for BMI could reduce this confusion. This could facilitate advances in research on the effects of BMI on lower extremity alignment.

Thus, the present study sought to investigate whether a higher BMI is associated with an increased incidence of postoperative misalignment and worse clinical function after TKA according to WHO grading for BMI. We present the following article in accordance with the STROBE reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-3212/rc).

Methods

Patients

In our retrospective cohort study, we performed a retrospective review of all patients undergoing primary TKA from January 2010 to December 2015 at our hospital. During this period, 820 cemented TKAs were performed. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Institutional Review Board of West

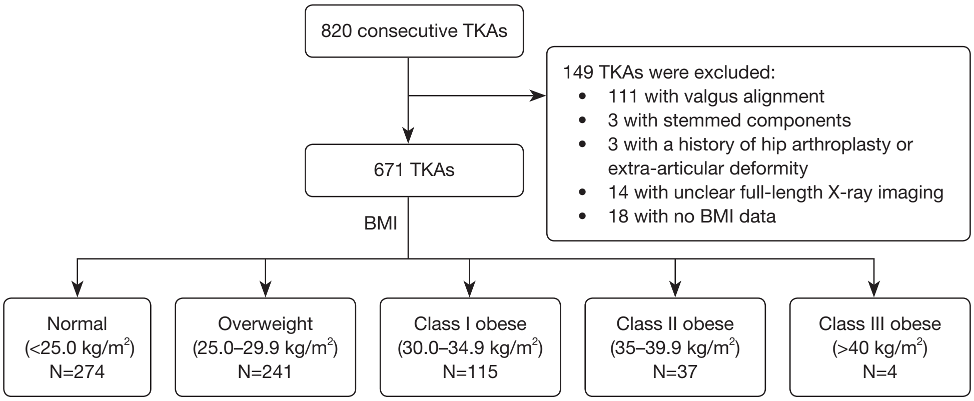

Figure 1 Study flowchart. BMI, body mass index; TKA, total knee arthroplasty.

China Hospital of Sichuan University (No. 2012-268). Written informed consent was obtained from each patient. The number of cases at our hospital during the study period determined the sample size. To be eligible for inclusion in the study, patients had to meet the following inclusion criteria: (I) have primary TKA due to primary knee osteoarthritis (diagnosed by an experienced orthopedic surgeon); (II) have undergone surgery, which was performed by 1 surgeon; (III) have complete full-length pre- and postoperative hip-ankle X-ray imaging available; and (IV) have complete clinical and demographic data and contact information available. Patients with valgus alignment, stemmed components, a history of hip arthroplasty or extra-articular deformity that could affect ipsilateral limb alignment, unclear full-length X-ray imaging, no BMI data, and excessive changes in BMI were excluded from the study (*Figure 1*). There was no significant difference in the preoperative clinical and radiographic measurements between each group.

The patients were divided into the following 5 groups: normal weight (<25.0 kg/m^2), overweight (25.0–29.9 kg/m^2), class I obese (30.0–34.9 kg/m^2), class II obese (35–39.9 kg/m^2), and class III obese (>40 kg/m^2) (19).

Surgical technique

The same surgical technique was used for all patients. All the operations were performed by the same surgeon using a Sigma fixed or rotating plant posterior-stabilized total knee prosthesis (PFC, Johnson & Johnson/DePuy, Warsaw, IN, USA). A midline skin incision was performed, and a medial parapatellar approach was adopted. After retracing the patella, the surgeon completely resected the anterior cruciate ligaments and meniscus. Osteotomy was performed using an intramedullary jig for the distal femur and an extramedullary jig for the proximal tibia, and the valgus angle during osteotomy was determined according to the preoperative full-length radiographs to achieve neutral alignment.

Intramedullary guides were positioned on the femoral side using Whiteside's line and the anatomical trans-epicondylar axis as landmarks, while extramedullary guides were positioned on the tibial side using the center of the tibial intercondylar eminence and the center of the ankle. The tibia was cut, the posterior cruciate ligament was resected, and soft tissue was released according to the degree of preoperative flexion contraction. Depending on the patient's degree of varus, polyethylene spacers of varying thickness were inserted, or additional soft tissue was released. All patients received a cemented total knee prosthesis and underwent patelloplasty without patellar resurfacing.

Radiographic assessment

Mechanical HKA was measured in all patients before and after TKA based on full-length radiography, which was conducted while patients were standing, and the patella was facing forward. X-ray images were taken postoperatively at 1 and 6 months, 1 year, and every 2–3 years thereafter. HKA was defined according to the criteria established by Cooke *et al.* (20) (*Figure 2*). Preoperatively, the center of the knee was defined as the intersection of the midline between the tibial spines and the midline between the femoral condyles and the tip of the tibia. The ankle center was taken as the middle of the talus roll at the level of the joint

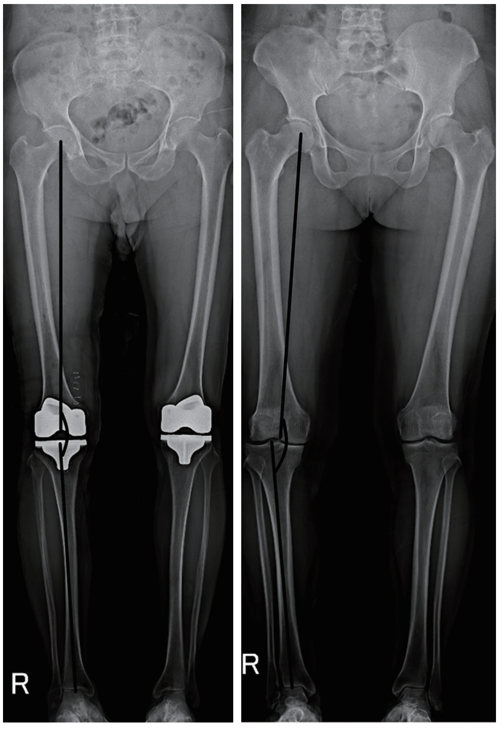

Figure 2 HKA angle as measured on a standing, full-length hip-to-ankle X-ray. R, right; HKA, hip-knee-ankle angle.

gap (21). HKA was expressed as the deviation from 180°, with positive values indicating valgus and negative values indicating varus alignment. Based on the postoperative HKA, knee alignment was classified as valgus (HKA >3°), neutral (−3°≤ HKA ≤3°), and varus (HKA <−3°).

Radiolucent lines progressing beyond 2 mm and the gross shifting of the implant components causing subsidence or tilting were defined as aseptic loosening (22). Mechanical failures, including aseptic loosening, polyethylene wear, and instability requiring revision surgery were considered the endpoints when analyzing implant survival (23).

Follow-up and outcome assessment

A total of 142 of the patients were lost to follow-up; thus, the final analysis contained 529 knees. We compared the knee function of the subgroups after stratifying by BMI. The included patients had the same BMI groupings at follow-up as the initial groupings.

All patients were followed up by telephone and questionnaire forms. At follow-up, we measured the functional score of patients, including the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score, Knee Society Knee (KSS) score, Knee Society-Function Score (KS-FS), Forgotten Joint Score (FJS), and range of motion (ROM). All patients were functionally scored in the form of a questionnaire. We believe that the selected rating scales are adequate to comprehensively reflect the degree of joint prosthesis function in patients' daily life.

The WOMAC comprises 24 items that cover 3 dimensions (i.e., pain, stiffness, and function) to measure dysfunction and pain associated. Higher scores indicate worse knee function. This self-assessment multidimensional instrument has been well studied, and many of its psychometric properties are known (24), and is also considered suitable to predict postoperative outcomes (25).

The KSS, a joint-specific outcome, is divided into 2 parts (i.e., the KS-KS and KS-FS) and helps exclude knee deterioration due simply to natural aging (26). KSS is a validated scoring systems to reflect the functional ability of the joints. Specific parameters assessed by the knee score section were pain (50 points), range of motion (25 points), and stability (25 points), with deduction of flexion contractures, extensor lag, and malalignment. Higher KSS scores indicate better knee function.

The FJS-12 is a 12-item questionnaire assessing patients' awareness of the joint during different activities of daily living (27). It measures patients' ability to forget the artificial joint in everyday life, and thus this index may be associated with patient satisfaction (27). The ability to forget artificial joints in everyday life can be regarded as the goal of arthroplasty, thereby satisfying the patient as much as possible. Higher FJS scores indicate a better ability to forget the artificial knee joint.

Statistical analysis

All the analyses were performed in SPSS 26.0 (IBM, Armonk, NY, USA). The normally distributed data are expressed as the mean ± standard deviation (SD), otherwise the data are expressed as the median (25th percentile, 75th percentile). A multivariate linear regression analysis was performed to examine the potential effects of sex, knee side, BMI, and preoperative HKA on postoperative HKA (6). A logistic regression was conducted to examine the contribution of these risk factors to the risk of misalignment in this patient population.

Differences in continuous data, such as age, follow-up duration, HKA, ROM, WOMAC, KSS, and FJS, among different BMI subgroups were assessed for significance

Table 1 Demographic and clinical characteristics of patients who underwent TKA stratified by BMI

Characteristic	BMI group[a]				
	Normal weight (n=274)[b]	Overweight (n=241)[b]	Class I obese (n=115)[b]	Class II obese (n=37)[b]	Class III obese (n=4)[b]
Sex					
Male	60 (21.9)	45 (18.7)	18 (15.7)	5 (13.5)	1 (25.0)
Female	214 (78.1)	196 (81.3)	97 (84.3)	32 (86.5)	3 (75.0)
Age (years)	67.4±8.14	66.4±6.70	64.1±5.93	60.0±3.56	64.0±4.23
BMI (kg/m^2)	22.4±1.86	27.2±1.26	31.6±1.40	35.7±0.43	44.1±0.98
Knee side					
Right	135 (49.3)	113 (46.9)	56 (48.7)	16 (43.2)	1 (25.0)
Left	139 (50.7)	128 (53.1)	59 (51.3)	21 (56.8)	3 (75.0)
Preoperative HKA (°)	–8.77±5.42	–8.81±5.26	–8.07±4.73	–11.47±2.60	–9.71±1.27

Values are n (%) or mean ± SD. [a], stratified according to the World Health Organization's BMI classification: normal weight (<25.0 kg/m^2), overweight (25.0–29.9 kg/m^2), class I obese (30.0–34.9 kg/m^2), class II obese (35–39.9 kg/m^2), and class III obese (>40 kg/m^2). [b], number of knees. TKA, total knee arthroplasty; HKA, hip-knee-ankle angle; SD, standard deviation; BMI, body mass index.

using an analysis of variance or the Kruskal-Wallis test as appropriate. Differences in categorical data, such as the incidence of misalignment and sex, were compared using the chi-squared test. Differences with two-sided P values <0.05 were considered significant.

Bias

The inclusion of patients with too much BMI change preoperatively versus at the follow-up may have led to bias; thus, we excluded patients whose BMI grouping changed at the time of follow-up. Additionally, to avoid bias, the researchers responsible for collecting data were blinded to the group allocation.

Results

Clinical and demographic characteristics of patients

In total, 671 knees were included in our study. The patients were divided into 5 groups according to their BMI, such that 40.8% of the knees belonged to patients with normal weight, 35.9% to overweight patients, 17.1% to class I obese patients, 5.6% to class II obese patients, and 0.6% to class III obese patients. The preoperative baseline clinical and demographic characteristics of the patients grouped by BMI, and the distribution of patient alignment based on BMI are detailed in *Table 1*. We followed-up the knee function of the included patients. A total of 142 patients were lost to follow-up because they could not be contacted when investigating patient knee function. Because we censored out the lost to follow-up population before inclusion in the analysis of knee function when comparing knee function across BMI subgroups, this did not affect our results. Thus, the final analysis contained 529 knees. The mean follow-up time was 8.16 years (±1.45 years).

Association between BMI and postoperative alignment

Patients' postoperative alignments are set out in *Table 2*. We separately compared the postoperative alignment of each BMI subgroup to the normal group. Neither the overweight (P=0.472) nor class III obese (P=0.091) groups differed from the normal group. There were significant differences between the class I obese (P=0.001), class II obese (P=0.008), and normal groups. Of the 671 knees included in the study, 492 knees (73.3%) were corrected to neutral alignment and 179 (26.7%) were unable to be corrected to neutral alignment. Of the 179 uncorrected to neutral knees, 4 (2.2%) had valgus deviations and 175 (97.8%) had varus deviations. The maximum residual varus was –11.4°, and the maximum valgus was +4.6° (*Figure 3*).

The Kruskal-Wallis test revealed that there was a strong correlation between an increased incidence of misalignment and a higher BMI (H =7.706; P<0.01). The multivariate regression revealed that postoperative alignment was negatively affected by preoperative alignment and BMI,

Table 2 Postoperative knee alignment in patients who underwent TKA stratified by BMI

Radiographic measurement	Normal (n=274)	Overweight (n=241)	Obese class I (n=115)	Obese class II (n=37)	Obese class III (n=4)
Postoperative HKA (°)	−2.68±2.291	−2.76±2.241	−4.37±2.276	−5.92±3.403	−5.87±0.157
Knees well-aligned[a]	238 (86.9)	204 (84.6)	84 (73.0)	26 (70.3)	2 (50.0)
Knees misaligned[a]	36 (13.1)	37 (15.4)	31 (27.0)	11 (29.7)	2 (50.0)
P value[b]		0.472[c]	0.001[c]	0.008[c]	0.091[d]

Values are n (%) or mean ± SD. [a], well-aligned was defined as 0 ± 3°; otherwise, knees were defined as misaligned; [b], comparison of each BMI subgroup to the normal group; [c], based on the Pearson chi-square test; [d], based on Fisher's exact test. HKA, hip-knee-ankle angle; n, number of knees; SD, standard deviation; TKA, total knee arthroplasty; BMI, body mass index.

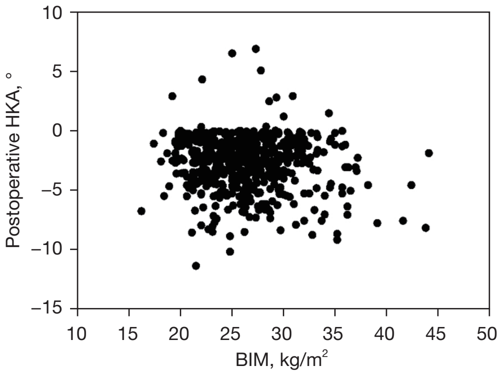

Figure 3 Correlation between postoperative HKA angle and BMI. HKA, hip-knee-ankle angle; BMI, body mass index.

Table 3 Multivariate regression to identify factors affecting post-surgical low limb alignment in patients who underwent TKA

Factor	P value*
Sex	0.324
Knee side	0.309
BMI	0.015
Preoperative HKA	0.002

*, based on multivariate regression analysis. TKA, total knee arthroplasty; BMI, body mass index; HKA, hip-knee-ankle angle.

but it did not depend on sex or knee side (*Table 3*). The logistic regression supported these findings, indicating that preoperative alignment and an increasing BMI were associated with an increased risk of post-surgical misalignment.

Association between BMI and knee function

As stated above, 142 knees of the 671 knees were lost to follow-up; thus, we compared knee function among the remaining 529 knees. ROM (P=0.688) and KS-FS (P=0.584) were similar among the BMI subgroups, while the WOMAC (P=0.022) score was significantly higher in the normal weight and overweight groups than the obese groups (*Table 4*). FJS (P=0.032), and KS-KS (P=0.001) gradually decreased as BMI increased.

No mechanical malfunctions occurred among patients in the normal, overweight, or class I obese subgroups. In this study, 2 mechanical malfunctions were observed; 1 in a class II obese patient, and the other in a class III obese patient.

Discussion

Our study was the first to adopt the WHO classification criteria to investigate the effect of BMI on lower extremity alignment. We also employed the WOMAC, KS-KS, KS-FS, FJS and ROM to assess the effect of BMI on long-term functioning in patients. To our knowledge, we undertook the most comprehensive examination of scoring to date in this study. We found that higher degrees of obesity stratified according to the WHO BMI grading system led to worse lower limb alignment and worse clinical function after TKA.

TKA can improve knee function in obese patients; however, concerns exist as to whether such patients face a higher risk of wound healing problems, infections, or long-term failure after the procedure (7,12,28). In all TKA patients, misalignment outside the "safe zone" of the mechanically neutral alignment may place increased shear stress on the polyethylene implant components, which in turn may lead to excessive wear and premature aseptic loosening (5,29). The risk of these outcomes may be even higher among TKA patients who are obese (6). In primary TKA, mechanical extra-medullary guides rely on palpable anatomic landmarks to determine tibial component positioning, which may be more difficult to determine

Table 4 Functional outcomes after TKA for knees stratified by BMI

Score or outcome	Normal (n=212)	Overweight (n=195)	Class I obese (n=97)	Class II obese (n=23)	Class III obese (n=2)	P value*
Range of motion (°)	99.50±7.619	95.56±15.519	94.82±16.898	90.00±7.071	89.29±13.271	0.688
WOMAC score	11.75±13.049	11.95±8.637	15.80±10.402	16.22±15.772	28.50±14.782	0.022
KS-KS	114.31±35.248	90.72±19.433	84.48±10.297	81.60±8.792	69.40±24.333	0.001
KS-FS	86.40±8.656	73.89±16.055	78.926±21.989	72.60±12.198	66.23±16.784	0.584
FJS	81.25±15.113	77.53±21.874	72.51±27.260	62.40±34.658	54.21±31.279	0.032

Data are presented as mean ± SD. *, based on multivariate regression analysis. TKA, total knee arthroplasty; BMI, body mass index; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index; KS-KS, Knee Society-Knee Score; KS-FS, Knee Society-Function Score; FJS, Forgotten Joint Score.

in obese patients with excessive soft tissue over the leg and ankle (15). The thick soft tissue envelope in obese patients may make surgical exposure difficult, obscure bony landmarks, and obstruct accurate positioning of cutting guides (30).

Our study found that patients with a higher BMI were more likely to suffer poor lower limb alignment, which led to a larger proportion of patients with postoperative residual varus. Similarly, a previous study (31) showed that a higher BMI makes neutral alignment more difficult to achieve using mechanical, intramedullary femoral guides, and extramedullary tibial guides. We and others use a surgical approach with intramedullary femoral and extramedullary tibial guides. When working with TKA patients who have a high BMI, especially those who are morbidly obese, we suggest that surgeons be prepared to rely on alternative methods for determining limb alignment in the event that adipose tissue obscures the traditional bony landmarks. In recent years, computer-guided TKA has become an alternative method for improving alignment (32). However, it may lead to erroneous measurements in obese patients due to difficulties in registering the femoral head center because of the substantial weight of the leg, and in registering the ankle center due to difficulties in palpating the malleoli. Conversely, a previous study (16) reported that the rate of patients falling outside the "safe zone" was similar between obese and non-obese patients (7.5% *vs.* 6.2%) in computer-assisted TKA. Thus, while obesity may not be an indication for using computer navigation during TKA, it can help to achieve consistently accurate limb and component alignment in obese patients. However, the issue of registration or the effect of reduced adipose tissue in the silico identification of bony landmarks needs to be addressed.

A second major finding of our study is that functional scores decreased with a higher BMI, which suggests that patients with a higher BMI have worse knee clinical function and are less likely to forget about the artificial knee joint, which may contribute to lower satisfaction. Previous studies on the relationship between BMI and TKA have largely focused on the incidence of postoperative infection and prosthetic survival times and have ignored the effect of BMI on joint function. Maniar *et al.* (33) suggested comparable knee function between class I obese patients and non-obese patients, but lower long-term knee function in class II obese patients. Conversely, another study (34) found no significant differences in knee function among different BMI groups. Stevens-Lapsley *et al.* (35) found no relationship between functional recovery and a BMI <40 up to 6 months after TKA. In a retrospective study of 988 patients, Stock *et al.* (36) confirmed that among patients with low preoperative BMI, the Patient-Reported Outcomes Measurement Information System-Physical Function scores of total hip arthroplasty and TKA patients were significantly improved. To the best of our knowledge, these studies either had a short follow-up period or employed few scoring systems, which may not adequately represent how well patients adapt to the sham knee. A great strength of our study is the adoption of the FJS scoring system. The FJS measures patients' ability to forget the artificial joint in everyday life, and thus this index may be associated with patient satisfaction (27). We consider this a better response to the patient's degree of endorsement of the false knee.

Our study had some limitations. First, our BMI subgroups were small; thus, our results need to be verified and extended in larger samples. In particular, our small subgroups meant that we could not reliably assess a number of factors (e.g., whether an increasing BMI was associated with a higher risk of poor alignment). Second, the same surgeon performed all the procedures in our study, which helped reduce confounding bias but may not reflect real clinical situations in which clinician experience may affect outcomes.

Conclusions

Despite its limitations, our study suggests that a higher BMI is associated with a greater risk of misalignment after TKA. In patients with postoperative residual varus, class II obesity (35–40 kg/m^2) and class III obesity (>40 kg/m^2) may be associated with worse long-term clinical outcomes. However, long-term prosthetic survival may not depend on BMI.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-3212/rc

Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-22-3212/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-3212/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Institutional Review Board of West China Hospital of Sichuan University (No. 2012-268). Written informed consent was obtained from each patient.

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