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Original Research

# Robotic-Assisted Total Knee Arthroplasty in Obese Patients

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A B S T R A C T

*Background:* Robotic-assisted systems have gained popularity in total knee arthroplasty (TKA). The purpose of this study was to evaluate operative characteristics and radiographic outcomes of obese patients undergoing robotic-assisted TKA.

*Methods:* A retrospective review of consecutive cases performed by a single surgeon was performed from January 1, 2016, to January 31, 2022. Adult patients with body mass index $\geq$35 kg/m$^2$ who underwent primary TKA using a computed tomography–assisted robotic system were compared to patients who underwent primary TKA using conventional instrumentation. Demographics, preoperative and postoperative radiographic measurements, and intraoperative outcomes were compared between cohorts. In total, 119 patients were identified, 60 in the robotic-assisted cohort and 59 in the conventional instrumentation cohort.

*Results:* Age, body mass index, and estimated blood loss were not significantly different between the cohorts. The robotic-assisted cohort experienced longer tourniquet times (93.3 vs 75.5 minutes, $P < .001$). Preoperative hip-knee-ankle angle (HKA) was similar between the robotic-assisted and conventional cohorts (8.4° ± 4.9° vs 9.3° ± 5.3°, $P = .335$). Postoperative HKA was 2.0° ± 1.4° in the robotic-assisted group and 3.1° ± 3.23° in the conventional group ($P = .040$). The proportion of patients with postoperative HKA > 3° of varus or valgus was 9 of 60 (15.0%) in the robotic-assisted cohort compared to 18 of 59 (30.5%) using conventional instrumentation ($P = .043$).

*Conclusions:* Obese patients treated with robotic-assisted TKA had postoperative alignment closer to neutral and fewer postoperative radiographic outliers than patients treated with conventional instrumentation. The results of this study support use of robotic-assisted technologies in TKA, particularly in obese patients.



## Introduction

Over 40% of United States adults are obese, which presents unique challenges in the development and treatment of osteoarthritis [1-4]. The increasing national prevalence of obesity coincides with a shift in the demographics of patients requiring total knee arthroplasty (TKA) [5]. Advanced computer navigation and robotic-assisted systems may have utility in TKA including improved component positioning, decreased soft-tissue trauma, and reduced postoperative pain when compared to conventional intramedullary femoral and extramedullary tibial guided approaches [6-15]. However, few studies have compared intraoperative differences between robotic-assisted and conventional systems in obese patients undergoing TKA [16-18].

Elevated body mass index (BMI) has been associated with increased component stress, component malalignment, and postoperative complications, such as aseptic loosening, periprosthetic joint infection, and superficial skin infection, when performing TKA [3,4,19,20]. Intraoperatively, excess adipose tissue can hinder surgical exposure and obscure intraoperative landmarks, thereby increasing the difficulty of obtaining appropriate alignment and component fixation [21,22]. Lastly, increased body mass results in increased stress at the fixation interface, thus increasing the risk of

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aseptic loosening especially in cases of component malpositioning [3,23].

Considering the difficulties encountered when performing TKA in obese patients, robotic-assisted surgery may prove more beneficial in this patient subset. Therefore, the purpose of this study was to compare preoperative and postoperative radiographic measurements between obese patients who underwent TKA with robotic-assisted or conventional systems, as well as to assess intraoperative outcomes such as duration of tourniquet use (tourniquet time [TT]), total operative time, and estimated blood loss (EBL).

## Material and methods

### *Study design*

All primary TKA cases performed from January 1, 2016, to January 31, 2022, by a single fellowship-trained orthopedic surgeon (D.A.O.) were identified. All surgeries were performed through a standard medial parapatellar approach and utilized a posterior stabilized implant. For patients who underwent TKA using conventional instrumentation, a measured resection distal femoral cut was performed 6° from the anatomic axis using an intramedullary sword to approximate a cut perpendicular to the mechanical axis of the femur. For all patients who underwent a TKA using standard instrumentation, the senior surgeon aimed for a neutral tibial cut. For patients who underwent a robotic TKA, the senior surgeon made the femoral and tibial cuts to obtain a neutral mechanical axis on postoperative hip-knee-ankle (HKA) films. The Mako Robotic-Arm Assisted Surgery system (Stryker Corporation, Kalamazoo, MI) was utilized for all robotic procedures. The orthopedic surgeon (D.A.O.) began using the Mako Robotic-Arm Assisted Surgery system in early 2016, whereas the first patient included in this study who underwent TKA with the robotic-assisted system was from April of 2018, after the learning curve and initial adoption of this robotic platform. The conventional instrumentation cohort underwent TKA from approximately 2016 to 2018, whereas the robotic-assisted cohort underwent TKA from approximately 2018 to 2021.

A retrospective chart review was performed to identify patient age, BMI at the time of surgery, and whether the procedure was performed using a computed tomography—assisted robotic system (robotic-assisted). Within this cohort, adult patients with a BMI greater than 35 kg/m$^2$ who underwent primary TKA using a robotic-assisted approach were identified. Adult patients with BMI greater than 35 kg/m$^2$ who underwent primary TKA using a conventional approach were identified as the control. Patients who were aged <18 years, underwent non-primary or non-elective TKA, lacked complete surgical records, or did not receive both preoperative and postoperative full-length radiographs were excluded.

Further retrospective chart review was performed to collect patient demographic information (eg, sex, American Society of Anesthesiologists [ASA] classification), preoperative details (eg, laterality, type of deformity [varus, valgus, neutral], range of motion, indication for TKA), and operative details (eg, date of surgery, TT, total operative time, EBL). TT was defined as the time from tourniquet inflation to tourniquet deflation. Total operative time was defined as the time from initial skin incision to completed skin closure. EBL was estimated per surgeon operative report. The HKA angle was measured on preoperative and postoperative full-length standing radiographs independently by one fellowship-trained orthopedic surgeon (R.M.D.) and one trained reviewer (M.K.R.) (Fig. 1). Varus angles were recorded as positive values, and valgus angles were recorded as negative values. Discordant measurements of >2° were assessed independently by a fellowship-trained orthopedic surgeon (N.D.H.). The 2 values for each measurement were then averaged.

The primary outcomes of interest were radiographic measurements, including postoperative HKA angle and the number of radiographic outliers within each cohort. Secondary outcomes included operative time, TT, and EBL.

The present study was conducted as approved by the institutional review board (IRB HS-14-00,107).

### *Statistical analysis*

Patient demographics, descriptive variables, and radiographic measurements are presented as means or percentages with standard deviations or ranges where appropriate. For radiographic measurements in which varus angles were recorded as positive values and valgus angles were recorded as negative values, the absolute value of measurements was used for comparative analyses. Normally and non-normally distributed continuous variables were compared using two-sample *t*-tests or Mann-Whitney U tests, respectively. Categorical variables were compared using chi-square analysis. Statistical analyses were performed using SPSS version 27 (IBM, Armonk, NY) with a significance of $P < .05$.

### *Study cohorts*

In total, 119 patients were identified of which 60 (50.4%) underwent a robotic-assisted TKA, and 59 (49.6%) underwent TKA via a conventional approach. There were no significant differences in patient age between the robotic-assisted TKA group and the conventional TKA (63.2 vs 63.8 years, $P = .651$). The average patient BMI was similar between cohorts (39.5 vs 39.3 kg/m$^2$, $P = .994$) (Table 1).

## Results

### *Patient characteristics*

There was a significant difference in ASA scores between the robotic-assisted group and the conventional group in terms of those assigned with an ASA score of 2 (33.3% vs 52.5%) and an ASA score of 3 (66.7% vs 47.5%, $P = .034$). No significant differences were found in sex (female: 78.3% vs 72.9%, $P = .489$), laterality (left: 45.0% vs 50.8%, $P = .523$), or preoperative deformity (varus: 76.7% vs 81.4%; valgus: 23.3% vs 18.6%, $P = .530$; Table 2).

### *Operative characteristics*

The robotic-assisted group experienced significantly longer TT than the conventional group (93.3 vs 75.5 minutes, $P < .001$). Total operative time was also significantly higher for the robotic-assisted group (180.8 vs 166.0 minutes, $P < .001$). However, there were no statistically significant differences in EBL between the 2 cohorts (69.6 vs 61.4 mL, $P = .057$) (Table 1).

### *Radiographic measurements*

Neither the robotic-assisted nor the conventional groups differed significantly in preoperative HKA angle (8.4° ± 4.9° vs 9.3° ± 5.3°, $P = .335$). Patients undergoing robotic-assisted TKA had postoperative HKA angles significantly closer to neutral than patients who underwent a conventional TKA (2.0° ± 1.4° vs 3.1° ± 3.2°, $P = .014$) (Table 3). In addition, the number of patients with postoperative HKA angles outside 0° ± 3° was found to be significantly lower for patients treated using the robotic-assisted

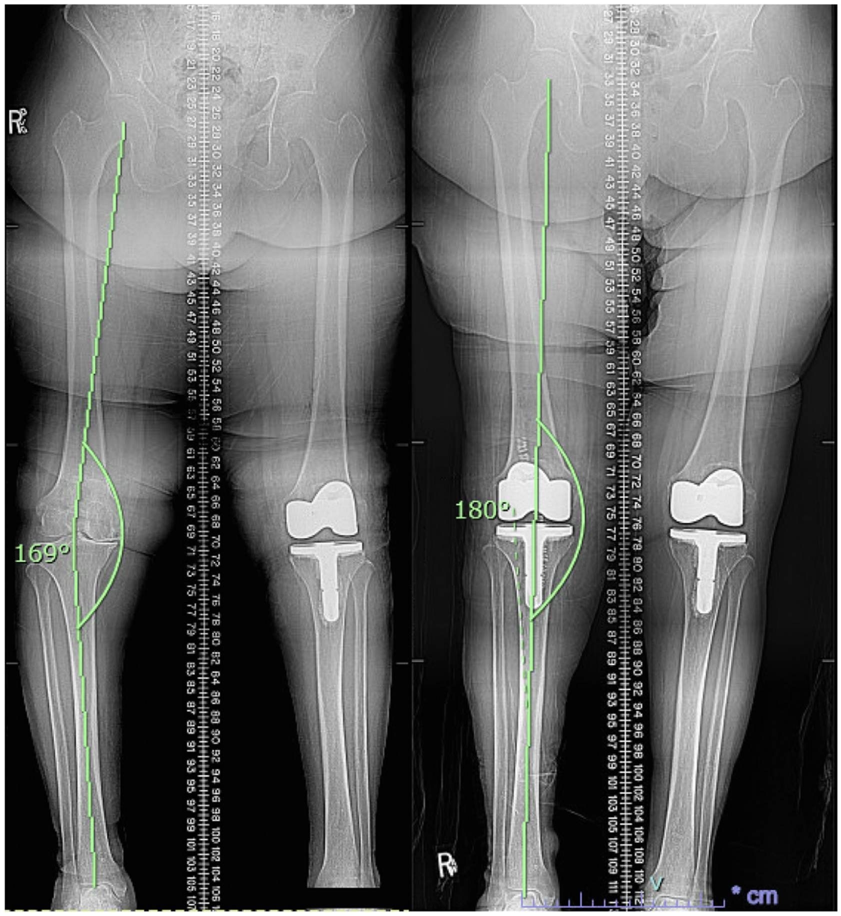


**Figure 1.** Preoperative and postoperative full-length anterior posterior radiographs of the same patient demonstrating a preoperative anatomic alignment (hip-knee-ankle angle) of 11° varus, and a postoperative anatomic alignment of 0°, prior to and following right total knee arthroplasty with conventional instrumentation. The left total knee arthroplasty was performed with conventional instrumentation and was also included in the present evaluation.

approach than with the conventional approach (9/60 vs 18/59, $P =$ .043) (Fig. 2).

## Discussion

Here we present the radiographic and intraoperative findings comparing obese patients who underwent TKA using a computed tomography–assisted robotic system to obese patients who underwent TKA using a conventional intramedullary femoral and extramedullary tibial-guided approach. There were similarities in both age and BMI between cohorts. The robotic-assisted cohort had similar EBL but longer TT and increased total operative time than the conventional cohort. Although preoperative HKA angles were similar, patients in the robotic-assisted cohort had postoperative HKA angles significantly closer to neutral anatomic alignment. Compared to the conventional cohort, patients who received robotic-assisted TKA were also less likely to have postoperative HKA angle outliers of >3° varus or valgus HKA angle. Overall, this study demonstrates using robotic-assisted systems may improve component accuracy and reduce coronal alignment outliers within a subset of patients with more challenging intraoperative exposure and anatomic landmark identification.

Utilization of robotic-assisted TKA entails a distinct intraoperative workflow with unique disadvantages. For example, the setup and registration of the robotic system is unique to robotic-assisted TKA, which may increase total surgical time [24]. For example, Tompkins et al. performed a propensity score–matched assessment of 2392 robotic and 2392 manually performed TKAs and found significantly increased procedure time as well as in-room to out-of-room operating time [25]. They reported robotic-assisted TKA required 78 minutes, and manual TKA required 70 minutes ($P < .0001$), and their room-in and room-out were 139 and

**Table 1**
Mean cohort age, body mass index, and operative details with comparisons between the robotic-assisted and traditional total knee arthroplasty approaches.

| Cohort characteristic | Total cohort, N = 119 | | | Robotic-assisted cohort, N = 60 | | | Traditional cohort, N = 59 | | | *P* value |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Standard deviation (STD) | Range | Mean | STD | Range | Mean | STD | Range | |
| Age (y) | 63.50 | 7.97 | 36-91 | 63.17 | 8.59 | 36-91 | 63.83 | 7.34 | 45-78 | .651 |
| Body mass index (kg/m$^2$) | 39.41 | 3.60 | 35-51 | 39.48 | 3.80 | 35-51 | 39.34 | 3.41 | 35-50 | .994 |
| Operative time (min) | 173.50 | 18.48 | 131-247 | 180.83 | 16.34 | 135-220 | 166.03 | 17.62 | 131-247 | **<.001** |
| Tourniquet time (min) | 84.58 | 13.08 | 45-130 | 93.33 | 9.87 | 76-130 | 75.53 | 9.29 | 45-100 | **<.001** |
| Estimated blood loss (mL) | 65.55 | 30.36 | 50-250 | 69.58 | 31.59 | 50-200 | 61.44 | 28.74 | 50-250 | .057 |

Bold values indicate statistical significance ($P < .05$).

**Table 2**
Frequency descriptives, including sex, laterality, preoperative deformity, and American Surgical Association (ASA) classification score, with comparisons between the robotic-assisted and traditional approaches.

| Cohort characteristic | Total cohort, N = 119 | | Robotic-assisted cohort, N = 60 | | Traditional cohort, N = 59 | | *P* value |
|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | |
| Sex | | | | | | | |
| Male | 29 | 24.37 | 13 | 21.67 | 16 | 27.12 | .489 |
| Female | 90 | 75.63 | 47 | 78.33 | 43 | 72.88 | |
| Laterality | | | | | | | |
| Left | 57 | 47.90 | 27 | 45.00 | 30 | 50.85 | .523 |
| Right | 62 | 52.10 | 33 | 55.00 | 29 | 49.15 | |
| Deformity | | | | | | | |
| Varus | 94 | 78.99 | 46 | 76.67 | 48 | 81.36 | .530 |
| Valgus | 25 | 21.01 | 14 | 23.33 | 11 | 18.64 | |
| ASA | | | | | | | |
| 2 | 51 | 42.86 | 20 | 33.33 | 31 | 52.54 | **.034** |
| 3 | 68 | 57.14 | 40 | 66.67 | 28 | 47.46 | |

Bold values indicate statistical significance ($P < .05$).

107 minutes, respectively ($P < .0001$). In the present study, we identified both an increased TT as well as overall operative time in the robotic-assisted cohort. In addition, a study by Pelkowski et al. described 36 patients who underwent both robotic-assisted and manual TKA in a crossover study of staged TKAs [26]. They found TT (73 vs 56 minutes) and operative time (116 vs 93 minutes) were significantly higher among their robotic-assisted procedures than among their manual procedures. The trends reported by Tompkins et al. [25] and Pelkowski et al. [26] resemble those reported in the present study in that robotic-assisted TKAs were significantly longer with respect to both TT and operative time. However, our reported operative times (180.8 vs 166.03 minutes) were higher than those reported by both studies, and our TTs (TT: 93.3 vs 75.5 minutes) were higher than those reported by Pelkowski et al. [26]. These differences are likely explained by the current study's focus on a specific subset of obese, high-risk, and anatomically challenging patients who likely require additional time for surgical exposure, soft-tissue balancing, and component placement.

Robotic-assisted systems may improve the accuracy and reproducibility of component positioning and overall limb alignment particularly for patients with challenging exposures or complex deformities [6,24,27,28]. Worsened radiographic limb alignment, particularly coronal plane varus or valgus malalignment >3°, has been associated with increased risk of aseptic loosening or radiographic lucencies [29-32]. This may be exacerbated in patients with elevated BMI, as this population experiences higher component shear stress [21,22,33]. Previous studies, such as an early randomized controlled trial from Song et al., showed significantly fewer radiographic outliers (defined as ± ≥3° of mechanical axis alignment) in their robotic-assisted cohort than in conventional TKA (0% vs 24%, $P < .001$) [8]. Of note, their analysis actively excluded patients with BMI of greater than 40 kg/m$^2$. However, even when optimal alignment is pursued, obese patients may still be at risk for aseptic loosening. For example, in a study of 5088 primary TKAs, Abdel et al. identified a two-fold increased risk of aseptic loosening among obese patients with a BMI greater than 35 kg/m$^2$, even with well-aligned constructs [19]. In addition, Ritter et al. performed an evaluation of 6070 TKAs and identified an increased failure rate in patients with a BMI greater than or equal to 41 kg/m$^2$ than in those with a BMI of 23 to 26 kg/m$^2$ [33]. This effect was exacerbated in patients with varus or valgus postoperatively aligned knees. In a study of 1106 patients, Fehring et al. found a cohort of 35 patients who experienced "catastrophic varus collapse" [34]. The average BMI of this subset was 40.5 kg/m$^2$. Overall, obese patients appear to be less tolerant of postoperative coronal misalignment.

Other studies examined radiographic alignment following robotic-assisted TKA comparing obese patients to non-obese patients. Puah et al. and Shetty et al. independently demonstrated that increased BMI was not associated with worse radiographic alignment outcomes following robotic-assisted TKA [35,36]. Puah et al. determined there was no relationship between a patient's BMI and their postoperative radiographic measurements in their study of 117 primary, computer-navigated TKAs [35]. Shetty et al. assessed 635 non-obese patients with BMI less than 30 kg/m$^2$ and compared them to 520 obese patients with BMI greater than or equal to 30 kg/m$^2$ [36]. They found no differences in postoperative limb alignment, component alignment, or outlier rates between cohorts. To our knowledge, there is only one published study assessing outcomes comparing a cohort of obese patients with BMI

**Table 3**
Radiographic descriptives including preoperative and postoperative hip-knee-ankle (HKA) angles with comparisons between the robotic-assisted and traditional approaches.

| Cohort characteristic | Total cohort, N = 119 | | | Robotic-assisted cohort, N = 60 | | | Traditional cohort, N = 59 | | | *P* value |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Standard deviation (STD) | Range | Mean | STD | Range | Mean | STD | Range | |
| Preoperative HKA (°) | 8.89 | 5.06 | 0.5-27 | 8.44 | 4.86 | 0.5-20.5 | 9.34 | 5.26 | 0.5-27 | .335 |
| Postoperative HKA (°) | 2.53 | 2.54 | 0-20 | 1.97 | 1.41 | 0-7.5 | 3.11 | 3.23 | 0-20 | **.040** |
| Net change in HKA (°) | 7.78 | 4.46 | 0-22.5 | 7.69 | 4.59 | 0.5-22.5 | 7.87 | 4.37 | 0-20.5 | 0.737 |
| | N | % | - | N | % | - | N | % | - | |
| Quantity with postoperative hip-knee-ankle angle outside 0° ± 3° | 27 | 22.69 | - | 51 | 85.00 | - | 41 | 69.49 | - | **.043** |
| Quantity with postoperative hip-knee-ankle angle within 0° ± 3° | 92 | 77.31 | - | 9 | 15.00 | - | 18 | 30.51 | - | |

Bold values indicate statistical significance ($P < .05$).

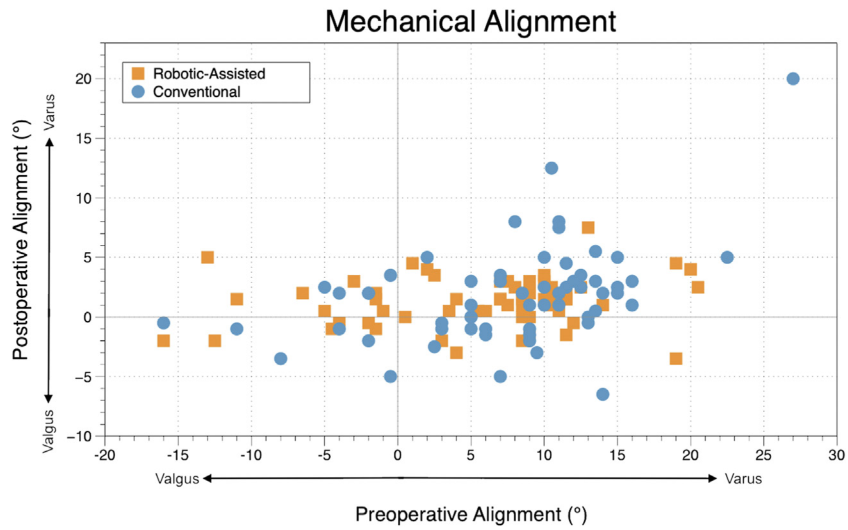


**Figure 2.** Preoperative vs postoperative hip-knee-ankle (HKA) angle measurements in degrees for robotic and conventional total knee arthroplasty (TKA) cohorts.

greater than 30 kg/m$^2$ who underwent robotic-assisted vs a cohort of obese patients with BMI greater than 30 kg/m$^2$ who underwent conventional TKA [37]. Kamat et al. [37] found 2 of 64 (3.1%) patients in the robotic-assisted cohort had malalignment >3° from a neutral mechanical axis compared to 16 of 74 (21.6%) in the conventional TKA cohort. In the present study, there were a significantly higher quantity of outliers among obese patients who underwent conventional TKA, which is consistent with that reported by Kamat et al. [37]. This being said, robotic-assisted TKA has not been demonstrated to provide superiority to conventional instrumentation in regard to patient-reported functional outcome scores [8,11,38-41]. Longer-term follow-up, larger sample size, and utilization of validated tools are needed to accurately assess for these outcomes [8,9,42,43]. Notably, a recent publication by Hickey et al. demonstrated that in order to identify the predicted relative reduction in revision rates attributable to robotic-assisted technology, a randomized-controlled trial would require each arm of the comparative study to include between 2500 and 4000 patients and would need to follow up patients for a minimum of 15 years [44]. This lengthy follow-up period and patient recruitment may not be logistically feasible among single-center or even multicenter studies without substantial investment and coordination.

There are several limitations to the present study. First, the cohorts were established based on 2 consecutive cohorts with a minimum BMI threshold, and although there were no differences in age, sex, BMI, laterality, and preoperative deformity between the 2 groups, there were differences in preoperative ASA, with the robotic-assisted group having a higher proportion of ASA 3 patients than the conventional instrumentation group. However, this identified difference would be unlikely to impact our radiographic findings, although we acknowledge that a randomized study design would have accounted for this difference in addition to other potential unobservable confounding factors. In addition, we recognize that utilization of a single-surgeon, single-institution method of evaluation potentially increases susceptibility to individual or institutional biases and limits the applicability of our findings. However, this same methodology also provides unmeasurable consistency and intrapatient reliability. Furthermore, the single-surgeon is a high-volume, fellowship-trained, and highly experienced surgeon, leading to additional credibility of the described findings. To avoid bias, all data collection and radiographic measurements were done without the input of the senior surgeon. Lastly, the primary focus of this evaluation was to assess radiographic outcomes of patients with an increased BMI who underwent robotic-assisted vs conventional-approach TKA. This study did not evaluate long-term outcomes such as implant durability, which remains an area of interest for future research by our study group.

## Conclusions

Obese patients treated with robotic-assisted TKA had postoperative alignment closer to neutral and fewer radiographic outliers than patients treated with conventional instrumentation. The results of this study demonstrate that robotic-assisted TKA may more reliably achieve radiographic alignment in obese patients and support the ongoing use of robotic-assisted technologies in TKA, although additional research with longer-term follow-up is necessary.

## Conflicts of interest

D.A. Oakes receives royalties from LimaCorporate and is a paid consultant for LimaCorporate; N.D. Heckmann receives royalties from Corin U.S.A; is a paid consultant for Intellijoint Surgical, MicroPort Orthopedics, Corin U.S.A, Zimmer; receives stock or stock options from Intellijoint Surgical; and is a Board member of AAOS, AJRR, and AAHKS; all other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2024.101320.

## CRediT authorship contribution statement

**Mary K. Richardson:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ryan M. DiGiovanni:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Brian K. McCrae:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Wesley S. Cooperman:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **John Ludington:** Writing – original draft, Methodology, Investigation, Formal analysis. **Nathanael D. Heckmann:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Daniel A. Oakes:** Writing

– review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

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