Arthroplasty Today 23 (2023) 101196

Contents lists available at ScienceDirect

Arthroplasty Today

journal homepage: http://www.arthroplastytoday.org/

Original Research

Robotic-Assisted Total Knee Arthroplasty Can Increase Frequency of Achieving Target Limb Alignment in Primary Total Knee Arthroplasty for Preoperative Valgus Deformity

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A R T I C L E I N F O

Article history:
Received 8 June 2023
Accepted 19 July 2023
Available online xxx

Keywords:
Total knee arthroplasty
Robotic
Manual
Alignment
Accuracy

A B S T R A C T

Background: Robotic-assisted total knee arthroplasty (rTKA) has been shown to reduce the number of alignment outliers and to improve component positioning compared to manual TKA (mTKA). The primary purpose of this investigation was to compare the frequency of achieving target postoperative limb alignment and component positioning for rTKA vs mTKA.

Methods: A retrospective comparative study was performed on 250 patients undergoing primary TKA by 2 fellowship-trained arthroplasty surgeons. Surgeon A performed predominantly rTKA (103 cases) with the ROSA system (Zimmer Biomet, Warsaw, IN) and less frequently mTKA (44 cases) with conventional instrumentation. Surgeon B performed only mTKA (103 cases). Target limb alignment for surgeon A was 0° for all cases and for surgeon B was 2° varus for varus knees and 0° for valgus knees. Radiographic measurements were determined by 2 reviewers. Target zone was set at ± 2 degrees from the predefined target.

Results: When comparing rTKA to mTKA performed by different surgeons, there were no differences in the percentage within the target zone (57.28% vs 53.40%, $P = .575$), but rTKA did result in a greater percentage for cases with preoperative valgus (71.42% vs 44.12%, $P = .031$). Patient-reported Outcomes Measurement Information System Global-10 physical scores were statistically higher at both 3 ($P = .016$) and 6 months ($P = .001$) postoperatively for rTKA compared to mTKA performed by different surgeons.

Conclusions: Although experienced surgeons can achieve target limb alignment correction with similar frequency when comparing rTKA to mTKA for all cases, rTKA may achieve target limb alignment with more accuracy for preoperative valgus deformity.

Level of Evidence: Retrospective Cohort Study, Level III.

Introduction

Despite continued improvements in surgical technique, implants, pain control, and rehabilitation protocols, up to 20% of patients remain dissatisfied following total knee arthroplasty (TKA) [1,2]. As public interest in robotic-assisted total joint surgery increases, there has been an increased use of robotic-assisted techniques with the goal of improving clinical and function outcomes, as well as implant longevity [3-6].

There is evidence to suggest that robotic technology in TKA may improve accuracy and precision of implant positioning to preoperative plan, while reducing trauma to periarticular soft tissues to enable improved early functional outcomes [7-11]. Cadaveric studies have demonstrated the ability of the ROSA knee system (Zimmer Biomet, Warsaw, IN) to achieve highly accurate bone cuts to match the surgeon's planned angles and resection thickness [12-14]. Counterarguments for the use of advanced technology include the learning curve of a new technique, equipment costs, and increased operative time [15,16]. Studies of high-volume surgeons using robotic technology demonstrated no superior clinical

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https://doi.org/10.1016/j.artd.2023.101196

outcome [17]. However, such technology may be useful in less experienced surgeons to achieve alignment goals with similar accuracy and precision as more established surgeons.

The primary purpose of this investigation was to compare the frequency of achieving target postoperative limb alignment and the accuracy to plan for component positioning in robotic-assisted TKA (rTKA) and manual TKA (mTKA) cases performed by 2 fellowship-trained arthroplasty surgeons. A secondary purpose was to compare the radiographic outcome differences between mTKA and rTKA cases performed by the same surgeon, as well as to evaluate functional outcome differences between the groups. The authors hypothesized rTKA would result in a greater frequency of cases within the target zone for postoperative limb alignment and component positioning, as well as improved short-term functional outcomes.

Material and methods

This is a single-institution retrospective review of 250 primary TKA cases performed by 2 fellowship-trained arthroplasty surgeons from March 2019 to October 2022. Surgeon A more frequently used a robotic-assisted technique (ROSA knee system, Zimmer Biomet, Warsaw, IN) and less frequently performed mTKA with conventional instrumentation. Surgeon B only performs mTKA with conventional instrumentation. Standard institutional review board approval was received from the authors' institution.

Patient selection

All rTKA cases from surgeon A that had preoperative and postoperative weight-bearing knee and long-leg radiographs were selected. This resulted in 103 cases. The most recent 103 mTKA cases from surgeon B with appropriate imaging were selected for comparison. Additionally, there were 44 mTKA cases performed by surgeon A over this time that were identified with appropriate imaging. All surgeries were performed under tourniquet using a medial parapatellar arthrotomy. All implants were cemented using medial-stabilizing polyethylene (Zimmer Biomet, Warsaw, IN). We excluded any patient who underwent conversion of a prior unicompartmental knee arthroplasty to TKA or any case that required revision components.

Data collection

All included patients had imaging to determine hip-knee-ankle angle. The target hip-knee-ankle angle for surgeon A was 0° in all cases and for surgeon B was based on their preoperative alignment (varus knees had a target of 2° varus and valgus knees had a target of 0°). Knee radiographs were evaluated in all patients using the Modern Knee Society Radiographic Evaluation System (Figure 1) [18]. Femoral component alpha angle target for surgeon A was neutral to the mechanical axis as planned by ROSA technology. Intramedullary guide with 3° of valgus femoral cut or 93° was used for surgeon A mTKA cases. The same manual femoral component alpha angle target of 93° was used for surgeon B. Tibial component beta angle target for surgeon A was perpendicular to the mechanical axis or 90°. For surgeon B, target beta angle was 88° (2° of varus) for varus knees and 90° for valgus knees. Both surgeons targeted tibial comment phi angles that matched the patient's native slope. Both surgeons had femoral component gamma angle targets that were case dependent based on flexion gap. The target zone was set at ± 2° from the predefined target. Alignment measurements were performed independently by 2 blinded reviewers. Patient demographics were obtained from chart review.

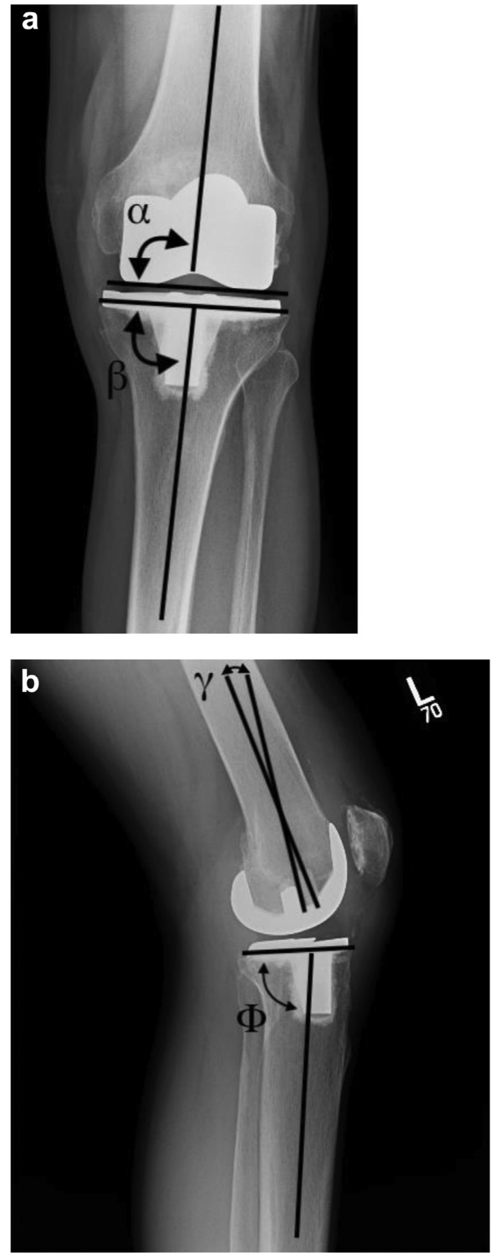

Figure 1. Anteroposterior and lateral left knee postoperative radiographs demonstrating measurement of the femoral and tibial component alignment in the (a) coronal plane (femoral alpha and tibial beta angles) and (b) sagittal plane (femoral gamma and tibial phi angles).

Patient-reported outcome measures (PROMs) were collected at preoperative, as well as 3- and 6-month postoperative visits using the Patient-Reported Outcomes Measurement Information System (PROMIS) Global-10 and Knee Injury and Osteoarthritis Outcome Score for Joint Replacement (KOOS JR) surveys.

Statistical analysis

All analyses were performed using SPSS Statistics software (v.23, IBM, Armonk, NY). For all parameters of interest, 2 separate analyses were made as follows: (analysis 1) surgeon A (rTKA) vs surgeon B (mTKA) and (analysis 2) surgeon A (rTKA) vs surgeon A (mTKA). For each analysis, an independent samples t-test was used to compare patient demographics and alignment measures between the 2 techniques. Chi-square analysis was used to compare frequency of postoperative alignment in the target zone (±2° from predefined target). Finally, for analyses 1 and 2, a 2 (surgeon) by 3 (timepoint) analysis of covariance (covaried on baseline measures and repeated on time) was used for within- and between-surgeon comparisons of PROMs with a Bonferroni post-hoc adjustment for individual pairwise comparisons. Type I Error was set alpha = 0.05 for all analyses.

Results

Analysis 1 − surgeon A (rTKA) vs surgeon B (mTKA)

Data for patient demographics, surgical time, and alignment measures are presented in Table 1. No differences in patient demographics (age, height, body mass index) were observed between patient groups for each surgeon. Surgeon B was observed to have lower total operating room and incision to closure times compared to surgeon A ($P < .001$). No difference between surgeons was observed for postoperative limb alignment measures or target zone accuracy for varus limbs. Among valgus limbs, surgeon A was observed to fall within the postoperative alignment target zone at a 27% higher frequency compared to surgeon B ($P = .031$) and was, on average, closer to the center of the target zone ($P = .032$).

For comparison of implant component alignment among varus limbs, differences were observed between surgeons for the alpha ($P < .001$), gamma ($P = .045$), and phi ($P < .001$) angles. For comparison among valgus limbs, a difference between surgeons was observed for the phi angle ($P = .001$). When comparing surgeons across all patients combined, differences were observed across all component angles ($P < .05$).

Comparison of PROMs for analysis 1 are shown in Figure 2. For the KOOS JR score (Figure 2a), both patient groups had similar improvements from preoperative to 3 months postoperatively ($P < .05$) that remained similar to those of 6 months postoperatively. For the PROMIS physical score (Figure 2b), only the patient group for surgeon A was observed to have significant improvements by 3 months postoperatively ($P < .001$) that were further elevated by 6 months postoperatively ($P = .037$).

Table 1
Patient demographics, surgical time, and alignment measures for Analysis 1.

Robotic-assisted (surgeon A) vs Manual (surgeon B)			
	Surgeon A, rTKA	Surgeon B, mTKA	
N	103 (m = 41, f = 62)	103 (m = 48, f = 55)	
Age (y)	66.11 ± 1.76	69.41 ± 1.55	
Height (m)	1.70 ± 0.03	1.70 ± 0.03	
BMI (kg/m^2)	33.28 ± 1.20	31.47 ± 1.17	
Total OR time (min)	168.53 ± 3.81	101.34 ± 2.25	$P < .001$
Incision to closure time (min)	124.55 ± 3.34	69.12 ± 1.91	$P < .001$
Alignment and alignment correction			
Preoperative varus (+)	72.82% (N = 75)	66.99% (N = 69)	
Preoperative alignment	6.92 ± 0.84	7.06 ± 0.98	ns, $P = .840$
Postoperative alignment	1.95 ± 0.58	2.75 ± 0.60	ns, $P = .063$
°Δ	5.29 ± 0.88	4.78 ± 0.79	ns, $P = .399$
% In 4° target range	52.00% (N = 39)	57.97% (N = 40)	ns, $P = .471$
Degrees from center of target	2.40 ± 0.48	2.05 ± 0.39	ns, $P = .272$
Preoperative valgus (−)	27.18% (N = 28)	33.01% (N = 34)	
Preoperative alignment	−6.73 ± 2.16	−8.58 ± 1.57	ns, $P = .170$
Postoperative alignment	0.24 ± 0.83	−0.60 ± 1.02	ns, $P = .236$
°Δ	7.27 ± 1.97	8.22 ± 1.72	ns, $P = .481$
% In 4° target range	71.42% (N = 20)	44.12% (N = 15)	$P = .031$
Degrees from center of target	1.64 ± 0.53	2.65 ± 0.68	$P = .032$
All patients	N = 103	N = 103	
% In 4° target range	57.28% (N = 59)	53.40% (N = 55)	ns, $P = .575$
Degrees from center of target	2.20 ± 0.39	2.25 ± 0.35	ns, $P = .845$
Postoperative component alignment			
Preoperative varus (+)	N = 75	N = 69	
Tibial component − **beta**	88.79 ± 0.44	89.36 ± 0.50	ns, $P = .093$
% In 4° target range	60.00% (N = 45)	44.93% (N = 31)	ns, $P = .070$
Degrees from center of target	1.82 ± 0.30	2.11 ± 0.33	ns, $P = .202$
Femoral component − **alpha**	95.23 ± 0.45	92.99 ± 0.49	$P < .001$
Femoral component − **gamma**	1.82 ± 0.25	1.46 ± 0.24	$P = .045$
Tibial component − **phi**	86.72 ± 0.48	83.24 ± 0.61	$P < .001$
Preoperative valgus (−)	N = 28	N = 34	
Tibial component − **beta**	89.34 ± 0.81	90.04 ± 0.83	ns, $P = .253$
% In 4° target range	67.86% (N = 19)	67.65% (N = 23)	ns, $P = .986$
Degrees from center of target	1.66 ± 0.55	1.82 ± 0.56	ns, $P = .706$
Femoral component − **alpha**	94.43 ± 0.67	94.09 ± 0.72	ns, $P = .509$
Femoral component − **gamma**	1.45 ± 0.30	1.26 ± 0.22	ns, $P = .300$
Tibial component − **phi**	87.13 ± 0.81	84.46 ± 1.16	$P = .001$
All patients	N = 103	N = 103	
Tibial component − **beta**	88.94 ± 0.39	89.59 ± 0.44	$P = .031$
% In 4° target range	63.11% (N = 65)	52.43% (N = 54)	ns, $P = .121$
Degrees from center of target	1.78 ± 0.26	2.01 ± 0.29	ns, $P = .237$
Femoral component − **alpha**	95.01 ± 0.38	93.35 ± 0.41	$P < .001$
Femoral component − **gamma**	1.72 ± 0.20	1.40 ± 0.18	$P = .017$
Tibial component − **phi**	86.83 ± 0.41	83.64 ± 0.57	$P < .001$

mTKA, manual total knee arthroplasty; OR, operating room; rTKA, robotic-assisted total knee arthroplasty.
Values expressed as means ± 95%CI or as frequencies (%).

Table 2
Patient demographics, surgical time, and alignment measures for analysis 2.

Robotic-assisted (surgeon A) vs manual (surgeon A)			
	Surgeon A, rTKA	Surgeon A, mTKA	
N	103 (m = 41, f = 62)	44 (m = 17, f = 27)	
Age (y)	66.11 ± 1.76	66.99 ± 2.48	
Height (m)	1.70 ± 0.03	1.69 ± 0.03	
BMI (kg/m^2)	33.28 ± 1.20	31.73 ± 1.76	
Total OR time (min)	168.53 ± 3.81	156.39 ± 5.08	$P < .001$
Incision to closure time (min)	124.55 ± 3.34	115.43 ± 5.20	$P < .001$
Alignment and alignment correction			
Preoperative varus (+)	72.82% (N = 75)	79.55% (N = 35)	
Preoperative alignment	6.92 ± 0.84	7.60 ± 1.32	ns, $P = .379$
Postoperative alignment	1.95 ± 0.58	1.55 ± 1.20	ns, $P = .510$
°Δ	5.29 ± 0.88	6.15 ± 1.30	ns, $P = .281$
% In 4° target range	52.00% (N = 39)	42.86% (N = 15)	ns, $P = .370$
Degrees from center of target	2.40 ± 0.48	3.07 ± 0.80	ns, $P = .072$
Preoperative valgus (−)	27.18% (N = 28)	20.45% (N = 9)	
Preoperative alignment	−6.73 ± 2.16	−8.92 ± 3.19	ns, $P = .307$
Postoperative alignment	0.24 ± 0.83	1.21 ± 1.52	ns, $P = .260$
°Δ	7.27 ± 1.97	10.13 ± 2.78	ns, $P = .144$
% In 4° target range	71.42% (N = 20)	55.56% (N = 5)	ns, $P = .376$
Degrees from center of target	1.64 ± 0.53	2.11 ± 0.93	ns, $P = .384$
All patients	N = 103	N = 44	
% In 4° target range	57.28% (N = 59)	45.45% (N = 20)	ns, $P = .188$
Degrees from center of target	2.20 ± 0.39	2.87 ± 0.67	$P = .035$
Postoperative component alignment			
Preoperative varus (+)	N = 75	N = 35	
Tibial component − **beta**	88.79 ± 0.44	89.70 ± 0.86	$P = .040$
% In 4° target range	60.00% (N = 45)	51.43% (N = 18)	ns, $P = .397$
Degrees from center of target	1.82 ± 0.30	2.10 ± 0.49	ns, $P = .331$
Femoral component − **alpha**	95.23 ± 0.45	94.65 ± 0.75	ns, $P = .175$
Femoral component − **gamma**	1.82 ± 0.25	3.20 ± 0.82	$P < .001$
Tibial component − **phi**	86.72 ± 0.48	83.41 ± 0.77	$P < .001$
Preoperative valgus (−)	N = 28	N = 9	
Tibial component − **beta**	89.34 ± 0.81	88.47 ± 1.90	ns, $P = .336$
% In 4° target range	67.86% (N = 19)	44.44% (N = 4)	ns, $P = .208$
Degrees from center of target	1.66 ± 0.55	2.81 ± 0.96	$P = .046$
Femoral component − **alpha**	94.43 ± 0.67	94.12 ± 1.62	ns, $P = .676$
Femoral component − **gamma**	1.45 ± 0.30	1.97 ± 0.41	$P = .040$
Tibial component − **phi**	87.13 ± 0.81	84.56 ± 1.87	$P = .007$
All patients	N = 103	N = 44	
Tibial component − **beta**	88.94 ± 0.39	89.45 ± 0.79	ns, $P = .200$
% In 4° target range	63.11% (N = 65)	50.00% (N = 22)	ns, $P = .139$
Degrees from center of target	1.78 ± 0.26	2.25 ± 0.44	ns, $P = .061$
Femoral component − **alpha**	95.01 ± 0.38	94.54 ± 0.67	ns, $P = .203$
Femoral component − **gamma**	1.72 ± 0.20	2.95 ± 0.68	$P < .001$
Tibial component − **phi**	86.83 ± 0.41	83.64 ± 0.72	$P < .001$

mTKA, manual total knee arthroplasty; OR, operating room; rTKA, robotic-assisted total knee arthroplasty.
Values expressed as means ± 95% CI or as frequencies (%).

For the PROMIS mental score (Figure 2c), only the patient group for Surgeon B was observed to have a small, but significant within-group decrease in score compared to preoperative at 3- ($P = .001$) and 6-month ($P = .017$) postoperative periods.

Analysis 2 − surgeon A (rTKA) vs surgeon A (mTKA)

Data for patient demographics, surgical time, and alignment measures are presented in Table 2. No differences in patient demographics (age, height, body mass index) were observed between patient groups. Compared to mTKA cases, rTKA cases were observed, on average, to have increased odds ratio (~12 minutes, $P < .001$) and incision to closure (~9 minutes, $P < .001$) times.

No difference between rTKA and mTKA cases was observed for postoperative limb alignment measures or target zone accuracy for varus or valgus limbs analyzed independently. When analyzed across all patients combined, rTKA cases were observed to be closer to the center of the target zone compared to mTKA cases ($P = .035$).

For comparison of implant component alignment among varus limbs, differences between technique were observed for the beta ($P = .040$), gamma ($P < .001$), and phi ($P < .001$) angles. For valgus limbs, differences in component alignment between techniques were observed for the gamma ($P = .040$) and phi ($P = .007$) angles. For the beta angle, rTKA cases were observed to be closer to the center of the target zone on average ($P = .046$). When comparing techniques across all patients combined, differences in alignment were observed for the gamma ($P < .001$) and phi ($P < .001$) angles.

Comparison of PROMs for analysis 2 is shown in Figure 3. No group differences were observed between rTKA and mTKA cases with both groups having similar improvements from preoperative for the KOOS JR and PROMIS physical scores at both 3 and 6 months postoperatively ($P < .05$).

Discussion

This study primarily evaluated the results of 103 mTKA and 103 rTKA cases by 2 high-volume arthroplasty surgeons. For all cases regardless of preoperative deformity and for cases with preoperative varus deformity, there was no difference in the percentage of patients that fell within the target zone or in the degrees from the

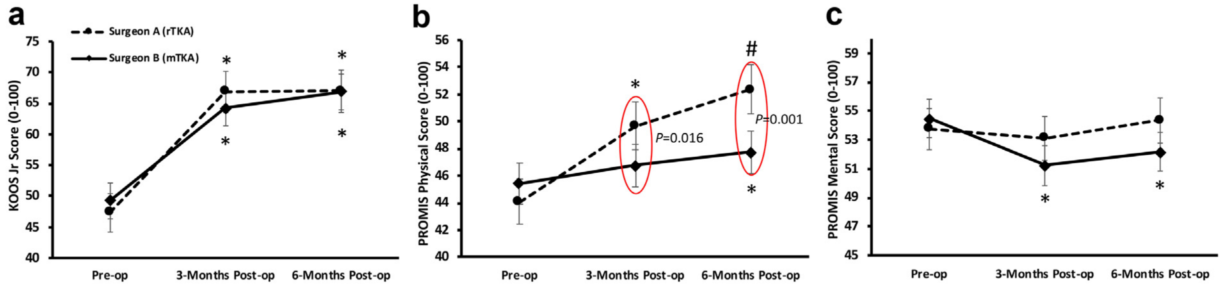

Figure 2. Data are presented as means ± SEM for patient reported outcomes comparing patient samples for surgeon A (rTKA) and surgeon B (mTKA) via the following surveys: (a) KOOS JR; (b) PROMIS Physical; (c) PROMIS Mental. * = Significant difference from pre-op within group; # = Significant difference from preoperatively and 3 months postoperatively within group; Circles around matched timepoints represent a significant difference between groups at the same matched timepoint. Type I error set at alpha = 0.05. KOOS JR, Knee Injury and Osteoarthritis Outcome Score for Joint Replacement; mTKA, manual total knee arthroplasty; rTKA, robotic-assisted total knee arthroplasty; PROMIS, Patient-Reported Outcomes Measurement Information System.

center of target for rTKA compared to mTKA. When evaluating only cases with preoperative valgus deformity, rTKA did result in a significant 27% increase of patients that fell within the 4° target range for postoperative limb alignment. Moreover, for valgus cases, rTKA did result in postoperative limb alignment that was significantly closer to the center of the surgeon's target. This finding indicates that although rTKA may not result in overall improved radiographic outcomes for a high-volume arthroplasty surgeon when looking at all cases, rTKA may have a role to improve precision and accuracy in more difficult cases or cases performed less frequently, such as preoperative valgus deformity.

The severe valgus knee has been reported to occur in 10% of TKA patients and is considered a surgical challenge due to lateral bone loss with metaphyseal remodeling (femoral condyle and tibial plateau), as well as tight lateral soft-tissue structures (iliotibial band, lateral collateral ligament, popliteus tendon, posterolateral capsule, and biceps femoris insertion) [19]. Previous authors have hypothesized that robotic-assisted techniques may not provide significant benefit to or be cost-effective for experienced high-volume TKA surgeons [20]. As rTKA becomes more prevalent in arthroplasty surgery due to potential advantages of component positioning, soft-tissue protection, and patient satisfaction [21], an increased understanding of the utility of rTKA compared to mTKA is needed. Prior authors have suggested rTKA can be of benefit in cases of severe coronal deformity to achieve a preoperatively planned neutral alignment [22]. Our findings support a role for rTKA to achieve target postoperative alignment more accurately in cases with preoperative valgus deformity.

When directly comparing rTKA to mTKA cases performed by the same surgeon, we found a nonsignificant 12% increase in frequency of patients within the target zone for rTKA. Notably, rTKA did result in a significant reduction in the degrees from the center of target, potentially demonstrating greater accuracy can be achieved with rTKA. Previous authors have reported rapid learning of robotic-assisted techniques with no difference in outcomes when compared to the same surgeon using a manual technique [23]. The ability of rTKA to place implants reproducibly and accurately according to the surgeon's planned resection and target component alignment will continue to draw surgeons to this technique [12-14]. The current study demonstrates rTKA can achieve target limb and component alignment with similar or greater accuracy when compared to mTKA for a single surgeon.

A potential downside to robotic-assisted techniques is the lack of long-term data to support improved clinical outcomes [24,25]. Short-term functional improvement has been reported with rTKA over mTKA [8,9]. We did demonstrate significantly improved KOOS JR scores for all patients at both 3 and 6 months postoperatively that exceeded the minimal clinically important difference [26-29], but there were no differences between groups. There was a significant difference in PROMIS physical function scores between rTKA and mTKA cases performed by different surgeons that may exceed the minimal clinically important difference [26,28,30], but this was not observed when evaluating rTKA and mTKA cases performed by the same surgeon.

Another downside to rTKA is increased duration of surgery, which is of particular interest when considering the effects of longer operative times on the rate of subsequent infection [31]. We found that surgical time and total operating room time were significantly greater for rTKA cases. However, when comparing rTKA to mTKA for the same surgeon, the times were much less at 12

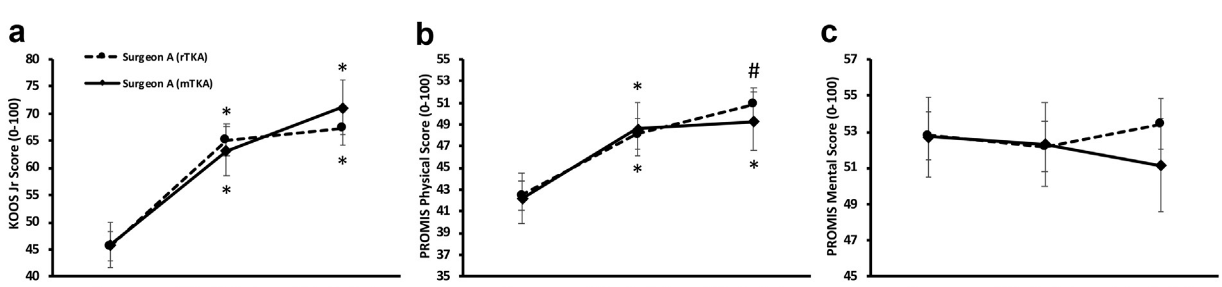

Figure 3. Data are presented as means ± SEM for patient reported outcomes comparing patient samples from surgeon A performing rTKA vs mTKA: (a) KOOS JR; (b) PROMIS Physical; (c) PROMIS Mental. * = Significant difference from pre-op within group; # = Significant difference from preoperatively and 3 months postoperatively within group. Type I error set at alpha = 0.05. KOOS JR, Knee Injury and Osteoarthritis Outcome Score for Joint Replacement; mTKA, manual total knee arthroplasty; rTKA, robotic-assisted total knee arthroplasty; PROMIS, Patient-Reported Outcomes Measurement Information System.

and 9 minutes longer for total operating room and surgical time, respectively. This is consistent with a prior study that reported a mean of 8 minutes of increased time is required to perform rTKA compared to mTKA [32]. Even if odds ratio efficiency can be achieved in robotic-assisted cases, experienced surgeons may not benefit from adoption of this technology for all cases [17]. Despite this, the improved reproducibility of rTKA for postoperative limb alignment in valgus cases and greater accuracy of rTKA for tibial component positioning in all cases suggest that rTKA may play an important role as TKA becomes more individualized with precise limb alignment and component positioning goals.

This study is limited by its retrospective design that primarily focuses on radiographic outcomes. Furthermore, reduction of the number of radiographic outliers during TKA has not translated into better implant survivorship [24]. Comparison of 2 surgeons with different alignment goals is another limitation. However, the optimal TKA alignment target is not known, and differing philosophies are still debated [33].

Conclusions

In summary, high-volume TKA surgeons can achieve target postoperative limb alignment with similar frequency when comparing rTKA to mTKA for all cases. On the other hand, as more precise limb alignment and component positioning goals are desired in TKA, rTKA may play an important role for achieving target postoperative limb alignment in more challenging cases, such as a valgus knee.

Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101196.

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