Making the transition from traditional to robotic-arm assisted TKA: What to expect? A single-surgeon comparative-analysis of the first-40 consecutive cases

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ABSTRACT

Objective/methods: We compared short-term outcomes following 40 traditional, cemented total knee arthroplasty (TKA) to the first 40 cemented robotic-arm assisted TKA (raTKA) and analyzed the learning curve for raTKA.

Results: LOS was longer for traditional TKA compared to raTKA (1.92 vs. 1.27days, $p < 0.0001$). There was no difference in surgical time between the second 20 raTKA and all traditional TKA cases (81.1 vs. 78.3 mins, $p = 0.254$). raTKA patients had improved 90-day ROM ($+3.8^\circ$ vs. -8.7° , $p < 0.05$) but comparable complications rates, Knee Society Scores, and patient-reported outcomes at all timepoints.

Conclusion: Despite comparable outcomes, the learning curve for raTKA appeared to progress rapidly.

1. Introduction

Total knee arthroplasty (TKA) is one of the most commonly performed orthopaedic surgical procedures, with nearly 600,000 primary TKAs performed annually in the United States.¹ The prevalence of primary TKAs has also increased over the past few decades, tripling between 1990 and 2002.² Advancement in technology has allowed for expanding indications for TKA bringing with it expectations for function and longevity once considered secondary goals. Despite advances in the field, traditional TKA is still associated with numerous complications, such as weakness, stiffness, pain, implant failure, and patient dissatisfaction.³ Given the associated risk of malalignment with traditional TKA and its impact on accelerating the need for revision and decrease patient satisfaction,^{4–7} methods that can improve optimal prosthesis positioning are highly sought after.^{8,9}

Robotic-arm assisted technology has become increasingly popular in orthopaedic surgery in recent years, particularly in joint arthroplasty.^{10–13} Robotic technology intended to improve precision as well as safety of procedures such as total knee arthroplasty.¹⁴ It also allows for more extensive preoperative planning and provides a more patient-specific approach which has been shown to lead to increased alignment accuracy.¹⁵ In addition, robotic-arm assisted TKA (raTKA) has improved protection of surrounding soft tissue, including the posterior cruciate ligament (PCL) and other ligaments.¹⁶ Yet, historically,

there have been concerns about complexity and excessive operative time, mainly for newly trained surgeons.^{15,17,18} Therefore, examining the learning curve associated with raTKA and comparing the surgeon's robotics performance to his own traditional TKA have become crucial questions to answer.^{19,20} Moreover, the literature remains unclear on the impact of this learning curve on the rate of complications, clinical outcomes, and patients' satisfaction.

This study sought to compare demographics and short-term outcomes following consecutive traditional, cemented TKAs to a surgeon's first 40 consecutive cemented raTKAs. Specifically, we evaluated: (1) length of stay (LOS); (2) pre- and postoperative range of motion (ROM) and Knee Society Scores (KSS) and pre-to-postoperative difference in ROM and KSS; (3) intraoperative parameters (estimated blood loss [EBL] and time between skin incision and skin closure [skin-to-skin time]); (4) patient-reported outcome measures (Lower Extremity Activity Scale [LEAS] and hospital satisfaction survey at discharge); (5) postoperative radiographic alignment; and (6) complications through 90-day follow-up. Additionally, we analyzed the learning curve for raTKA in the first 40 cases.

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2. Methods

2.1. Study design

This study was a retrospective review of prospectively collected data on consecutively enrolled patients who underwent total knee arthroplasty (TKA) by a single, fellowship-trained surgeon. After the implementation of the Mako System (Stryker, Mahwah, NJ), the first 40 consecutive cemented robotic-arm assisted TKA (raTKA) cases performed following introduction were reviewed. Patients included were adults (> 18 years of age) who required primary TKA and were willing and able to comply with postoperative follow-up appointment requirements and self-evaluations. Patients were excluded from this study if they had one or more of the following conditions: $\geq 10^\circ$ varus or $\geq 10^\circ$ valgus flexion contracture, body mass index (BMI) > 40 kg/m², active or suspected infection in or about the joint, skeletal immaturity, inadequate bone stock to support prosthesis fixation, blood supply limitations, muscular atrophy, neuromuscular pathology, or vascular deficiency in the affected limb that render the procedure unjustified, mental or neurological conditions that may impact their capacity to follow instructions, collateral ligament insufficiency, or any prior high tibial osteotomy (HTO) or unicompartmental knee arthroplasty. This study was approved by the institutional review board of the senior author's institution.

2.2. Study population

Patients in the raTKA cohort were 1:1 matched by age, gender, BMI, comorbidities, and preoperative ROM with forty patients who had consecutively-performed traditional, manual cemented TKA. All patients underwent the same perioperative protocols, including preoperative acetaminophen and cyclooxygenase (COX)-2 inhibitors, an adductor nerve block, and intra- and peri-articular liposomal bupivacaine injections. Demographic data collected included age, sex, and BMI. By design, the raTKA cohort (n = 40) had comparable age (69.5 vs. 70.9 years), BMI (29.1 vs. 30.1 kg/m²), and gender distribution (both 60% female) to patients in the traditional TKA cohort (n = 40) (all p > 0.05).

2.3. Outcome measures

Full review of hospital and clinic medical records were performed to obtain information on demographic, preoperative, intraoperative, and postoperative measures. Preoperative data collection included ROM, 2011 KSS, and coronal radiographic alignment with respect to the mechanical axis. Intraoperative data collection included EBL and skin-to-skin time. Postoperative data collection included LOS, hospital satisfaction survey at discharge, and ROM, KSS, radiographic alignment, major and minor complications and Lower Extremity Activity Scale (LEAS) at 30-, 60-, and 90-day follow up time-points. Complications were defined as per Parvizi et al.²¹ and included: (1) systemic major complications, which may be life-threatening and require complex medical management (tachyarrhythmia, myocardial infarction, congestive heart failure, hypotensive crisis, cardiac arrest, pulmonary embolus, pneumothorax, acute renal failure, transient ischemic attack and/or stroke, bowel obstruction and/or perforation, or death); (2) local major complications, which may require additional surgical intervention or lead to temporary or permanent functional injury (peripheral nerve injury, vascular injury, compartment syndrome, or periprosthetic fracture); (3) systemic minor complications, (severe nausea and vomiting, *Clostridium difficile* infection, electrolyte imbalance, anemia, urinary tract infection, mental status change, gastric hypomotility, deep venous thrombosis, atelectasis, pneumonia, or others); and (4) local minor complications (superficial wound infection, persistent wound drainage, skin blisters, hematoma, or severe muscular spasm). Minor complications were those that may have required lengthened hospital

stay, additional observation, or additional medical management.²² The LEAS, developed by Saleh et al.,²³ is a validated, self-administered instrument to assess true patient activity levels; it is scored by patient selection of one of 18 described activity levels that correlate to a score of 1–18. The patient satisfaction score, utilizing the validated, reliable self-administered questionnaire developed by Mahomed et al.,²⁴ is the average of responses to four items, scored in a Likert scale (from 25 to 100, with a 25 corresponding to a response of “Very dissatisfied” and a 100 corresponding to a response of “Very satisfied”).

2.4. Statistical analysis

Univariate analysis applied parametric or non-parametric tests where applicable, to compare demographics, preoperative parameters, intraoperative parameters, and postoperative parameters between raTKA and traditional TKA groups. Additionally, the surgical time and EBL were compared between the first 20 and second 20 raTKA cases via paired student's t-test. All statistical analyses were completed using SPSS version 24.0 (IBM Corporation, Armonk, NY), with the threshold for statistical significance set at p < 0.05.

3. Results

The mean LOS was longer for the traditional TKA cohort compared to the raTKA cohort (1.92 vs. 1.27 days, p < 0.0001). Preoperatively, the raTKA cohort and traditional TKA cohort had comparable ROM (117.5° vs. 118.5°) and KSS (81.5 vs. 77.3), both p > 0.05 (Table 1).

Intraoperative EBL was comparable between raTKA and traditional TKA cohorts (42.4 vs. 49 ml, p = 0.448). However, the raTKA cohort required slightly greater overall surgical time than the traditional TKA cohort (82.5 vs. 78.3 min, p = 0.002). Importantly, there was no significant difference in surgical time when comparing the mean surgical time of the second 20 cases of raTKA to the traditional TKA group (81.1 min vs. 78.3 min, p = 0.254).

In evaluating pre-to postoperative differences in ROM and KSS, the raTKA cohort had improved ROM compared to the traditional TKA cohort at 90 days (+3.8° vs. −8.7°, p < 0.05). There was no statistically significant difference in postoperative KSS at 30, 60, and 90-day follow-up (Table 2, Table 3, and Table 4). Postoperative alignment was within +3.0° of the mechanical axis for all patients in both robotic-arm assisted and traditional TKA groups. At all follow-up time points, there was no significant difference in complications rate, both major (n = 1 [major local complication] in traditional TKA group, n = 0 in raTKA) or minor (n = 0 in both traditional TKA and raTKA groups).

With respect to patient-reported outcome measures, both cohorts reported comparable lower-extremity activity scale (LEAS) scores at preoperative, and 30-, 60-, and 90-day follow-up time points (Table 5). Additionally, hospital satisfaction survey results at discharge were comparable between the two cohorts (raTKA 89.06 vs. traditional TKA 86.91, p = 0.429).

Table 1

Demographics, length of stay, laterality, and preoperative range of motion (ROM) and Knee Society Scores (KSS) of patients who underwent robotic-arm assisted TKA and traditional TKA. The threshold for statistical significance was set to p < 0.05.

Parameter	Robotic-Arm Assisted TKA	Traditional TKA	p-value
N	40	40	–
Sex	24F:16M	24F:16M	–
Age (years)	69.5	70.9	0.551
BMI (kg/m ²)	29.1	30.1	0.383
Length of Stay (days)	1.27	1.92	< 0.001
Laterality (Right:Left)	23:17	21:19	0.658
Preoperative ROM (°)	117.5	118.5	0.461
Preoperative KSS	81.5	77.3	0.508

Table 2

30-day follow-up outcomes of patients who underwent robotic-arm assisted TKA and traditional TKA. The threshold for statistical significance was set to $p < 0.05$.

30-Day Follow-Up	Robotic-Arm Assisted TKA	Traditional TKA	p-value
Range of Motion (°)	107.9	114.5	0.028
Pre-to-Postoperative ROM Difference (°)	−9.6	−4.0	0.569
KSS	86.0	90.9	0.082
Pre-to-Postoperative KSS Difference	+4.5	+13.6	0.218
Minor Complication Rate	0.0%	0.0%	–
Minor Complications	None	None	–
Major Complication Rate	0.0%	2.5%	0.320
Major Complications	None	Arthrofibrosis requiring Manipulation under Anesthesia (MUA) (n = 1)	–

Table 3

60-day follow-up outcomes of patients who underwent robotic-arm assisted TKA and traditional TKA. The threshold for statistical significance was set to $p < 0.05$.

60-Day Follow-Up	Robotic-Arm Assisted TKA	Traditional TKA	p-value
Range of Motion (°)	118.1	118.8	0.697
Pre-to-Postoperative ROM Difference (°)	+0.6	+0.3	0.928
KSS	91.9	91.7	0.938
Pre-to-Postoperative KSS Difference	+10.4	+14.4	0.588
Minor Complication Rate	0.0%	0.0%	–
Minor Complications	None	None	–
Major Complication Rate	0.0%	0.0%	–
Major Complications	None	None	–

Table 4

Minimum 90-day follow-up outcomes of patients who underwent robotic-arm assisted TKA and traditional TKA. The threshold for statistical significance was set to $p < 0.05$.

90-Day Follow-Up	Robotic-Arm Assisted TKA	Traditional TKA	p-value
ROM (°)	121.3	109.8	0.076
Pre-to-Postoperative ROM Difference (°)	+3.8	−8.7	0.039
KSS	88.2	89.5	0.730
Pre-to-Postoperative KSS Difference	+6.7	+12.2	0.353
Minor Complication Rate	0.0%	0.0%	–
Minor Complications	None	None	–
Major Complication Rate	0.0%	0.0%	–
Major Complications	None	None	–

Table 5

Lower extremity activity scale at preoperative, 30-, 60-, and 90-day time-points compared between robotic-arm assisted and traditional total knee arthroplasty (TKA) cohorts. The threshold for statistical significance was set to $p < 0.05$.

Lower Extremity Activity Scale	Robotic-Arm Assisted TKA	Traditional TKA	p-value
Preoperative	8.47	8.27	0.529
30-Day	11.63	11.50	0.736
60-Day	12.06	11.65	0.271
90-Day	12.18	11.94	0.519

4. Discussion

Robotic-arm assisted surgery has demonstrated immense promise in potentially improving component placement precision, reducing complication rates, and achieving better soft tissue protection.^{16,25–27} Robotic-arm assisted technology also permits improved preoperative planning and may decrease complication rates.³ However, few studies had assessed the complications during the learning curve period or compared short-term outcomes between cemented raTKA and traditional manual cemented TKA.

This study demonstrated that while traditional TKA had longer length of stay, there was no difference between raTKA and traditional TKA with regards to alignment, range of motion (ROM), stability, and validated functional and patient-reported outcome measures, suggesting comparable short-term outcomes between the two procedures. Robotic-arm assisted TKA patients experienced a shorter LOS than traditional TKA patients, despite receiving identical perioperative protocols. With respect to raTKA learning curve, operative time (skin-to-skin time) improved in the latter half of a single surgeon's first 40 raTKA procedures, demonstrating a fairly expedient learning curve, in this case, of 20 cases. Interestingly, during this learning curve, there were no major or minor complications observed.

This study was not without its limitations. Due to the nature of the study, we were able to provide only early follow-up with perioperative outcomes. As we continue to follow this subset of patients we will be able to provide clarity on the mid- and long-term outcomes of these early cases. The second limitation is that this surgeon was not necessarily naïve to robotic-arm assisted surgery, since the surgeon had previously used this technology for UKA. This may have permitted an easier transition for its use with total knee arthroplasty. The third limitation is that this was a single surgeon series, though this may be perceived as a strength to some. The sample size was also small, but the length of the learning curve has been previously described in several related studies as up to 40 cases, thus this was the number chose for this study.^{19,28,29} Despite the small sample size, when compared to the traditional TKA group at 90 day post-operative, the raTKA group had improved ROM, reduced number of major and minor complications, and improved LEAS. A future clinical study with a larger dataset would be necessary to understand if the trends for improved outcomes persist.

The present study proposes 20 raTKA procedures as a critical cutoff in the learning curve of newly trained surgeons. Though limited in number, several studies in the literature have reported comparable results. In a prospective comparative study of 240 raTKA procedures performed by two high-volume orthopaedic surgeons with no prior experience with raTKA, Sodhi et al.²⁵ showed a significant decrease from the first 20 to the last 20 cases of raTKA for each surgeon, while also demonstrating no difference in operative time between the last 20 raTKA and manual TKA cases. Similarly, Coon et al.¹⁹ showed an improvement in tourniquet time from 80 to 120 min for initial cases to less than 40 min over the first 50 cases of raTKA. Hampp et al.³⁰ evaluated the stacked error of consecutive raTKA procedures in cadaveric knees performed by a single surgeon with no prior robotic-arm assisted surgical experience, reporting the greatest degree of error in tibial slope and implant positioning, among others, occurred during the first two cases. Keggi et al.³¹ reviewed the first raTKAs performed by a single surgeon with no prior experience with robotic-arm assisted surgery. Based on reduction in skin-to-skin time (83.7 vs. 57.1 min) and all other time metrics except for residual time, they reported a learning curve of nearly seven cases. The latter two studies both support the notion that orthopaedic surgeons can rapidly learn in a relatively short number of cases, despite no prior exposure to robotic-arm assisted technology. Yet, the present study distinguished itself from previous studies in the observation of no complications during the first forty raTKA cases, while also reporting a shorter learning curve of twenty cases.

With respect to other outcomes studied, the literature also supports the findings of the present study. Song et al.³² also found no difference

in clinical scores, complications, and postoperative ROM in a cohort that underwent robotic-assisted TKA compared to those who underwent traditional TKA. In the present study, the delta of additional ROM at 90 days postoperatively was better, but not statistically significant; this could have been due to optimal functional component placement or minimization of soft-tissue trauma, as no soft-tissue releases were needed in the raTKA cohort. Liow et al.³³ also showed that robotic-assisted TKA yielded postoperative coronal mechanical alignment to be within 3° of the mechanical axis, supporting the results of this study and the precision associated with raTKA. Moreover, they found no overall difference in short-term complications between the two groups, also similar to the findings of the present study in which there was no significant difference in total, major, or minor complications at 30-, 60-, and 90-day follow-up.³³ With respect to clinical and radiographic outcomes, similar results have been reported in the robotic assisted UKA literature. In a prior study by several authors of the present study, Naziri et al.³⁴ systematically reviewed the literature to compare rates of reoperation between robotic assisted UKA and computer-assisted UKA, demonstrating comparable revision rates between the two cohorts (5.0% vs. 3.9%, $p = 0.495$). Hansen et al.³⁵ retrospectively compared robotic assisted and manually-placed medial UKA in a matched set of patients, demonstrating excellent and low complication rates, while also yielded negligible differences in radiographic measures, including coronal alignment, femoral axis change, and postoperative tibial slope.

The results of the present study do, however, differ with other related reports in the literature. When considering complications during the learning curve, Park et al.³⁶ found a higher rate of soft tissue and fracture complications in early robotic assisted TKA cases; however, they reported these were due to improperly small skin incisions and size of frame pin insertions for fixation. Following adjustment to larger incision and use of smaller fixation pins resulted in no soft tissue or fracture complications. Of note, they utilized a different robotic planning and implantation system from the present study.³⁶ Considering radiographic alignment, although Liow et al.³³ reported similar robotic assisted TKA coronal knee alignment to the present study, they actually found robotic assisted TKA subjects to have improved mechanical alignment when compared to traditional TKA.

Therefore, the benefits of raTKA appear to be with respect to surgical precision and accuracy, and the ability to produce less outliers with regards to deformities.¹⁶ Moreover, combining these findings with the rapid learning curve observed, this study supports the notion that raTKA can be feasibly adapted by surgeons naïve to robotic-arm assisted surgery without concern of increased adverse outcomes or patient dissatisfaction.

5. Conclusions

The adaptation to new technologies in the field of orthopaedics at times can be a daunting task or an inconvenience to the routine of the established total joint surgeon. Not all new technologies provide demonstrable improvement to an already refined and proven operation. This study demonstrated comparable outcomes between first 40 raTKA and traditional TKA performed by a single surgeon. Importantly, the learning curve for raTKA appeared to progress rapidly, as the surgeon in this study reported comparable surgical time to his traditional TKA by his second set of 20 raTKA cases, with no complications observed. Adapting new technology can be at times associated with difficulty or increased complication rate. Our results are promising showing not only was there no increase in complications, we found there was early clinical improvement in the robotic assisted TKA group. This data supports the implementation of raTKA by surgeons who have had no prior exposure to raTKA. Future clinical study with a larger dataset is recommended to understand if the trends for improved raTKA outcomes persist.

Conflicts of interest

There are no relationships or conflicts of interest directly related to this paper or that could influence or bias this work. The following authors have no disclosures to report: Q.N., B.C.C., M.C., and N.V.S. The author A.S. is a consultant for Stryker, outside of the scope of this work and receives research support from Stryker.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jor.2019.03.010>.

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