Original research

Learning Curve of Robotic-Assisted Total Knee Arthroplasty for Non-Fellowship-Trained Orthopedic Surgeons

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ABSTRACT

Background: Total knee arthroplasty (TKA) serves as a reliable treatment option for patients with end-stage arthritis, but patient dissatisfaction rate remains high. With the projected increase in the volume of arthroplasty operations, surgeons have aimed for methods in which to improve the patient outcomes. Robotic-assisted TKA has become increasingly popular. The learning curve for such technology has been investigated, but these prior studies have only been performed by fellowship-trained arthroplasty surgeons. The goal of this study was to investigate the learning curve for non-fellowship-trained orthopedic surgeons to ameliorate any concerns about increased operative time.
Methods: Retrospective analysis of robotic-assisted TKAs and manual TKAs, performed by two non-fellowship-trained orthopedic surgeons, was conducted on a total of 160 patients. For each individual surgeon, the robotic-assisted TKAs were divided into 3 cohorts of 20 consecutive patients. Data from 20 consecutive manual TKAs were also gathered for each surgeon. The mean operative times were compared. Cohorts were then grouped together for both surgeons and compared in a similar fashion.
Results: For surgeon 1, mean operative times were significantly increased for robotic-assisted cohorts compared with those for the manual cohort. For surgeon 2, the first robotic-assisted cohort was significantly longer. However, there were no significant differences for the second and third robotic-assisted cohorts. In the combined surgeon group, there was no significant difference between operative times for the third robotic cohort and the manual cohort.
Conclusion: This study demonstrates that the general orthopedic surgeon in a community hospital may be able to adequately perform robotic-assisted surgery in a similar timeframe to their manual TKA within their first 40 robotic-arm-assisted TKA.
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Introduction

Total knee arthroplasty (TKA) is one of the most common orthopedic procedures performed in the United States, with a significant projected increase in primary TKAs performed by 2030 [1]. TKA is a reliable treatment option that provides pain relief, return of quality of life, and increased functionality in patients with symptomatic osteoarthritis. Satisfactory outcomes are achieved in most patients. Nevertheless, approximately one in five primary TKA patients are dissatisfied with their outcomes, with studies reporting patient dissatisfaction rates ranging from 18.2% to 19% [2-4]. Surgical techniques such as kinematic vs mechanical alignment, computer-assisted surgery vs patient-specific instrumentation, and cruciate retaining vs posterior stabilized implants have been extensively analyzed with the goal to improve outcomes [5]. A new field of promise is the utilization of robotic-arm-assisted TKA (RATKA). Regardless of surgical technique, optimal implant alignment is essential for implant longevity and patient satisfaction. Component coronal malalignment of greater than three degrees has been identified in 32% of conventional TKAs and can lead to pain and instability [6]. Implant alignment and soft-tissue balance

play a vital role in a patient's treatment success and the implant's survival [7].

Achieving the desired alignment and performing accurate gap balancing can be very challenging. Manual jig-based instruments have demonstrated variability and inaccuracy during primary TKA as the surgeon must use gap measurement blocks or laminar spreaders to assess the flexion and extension gaps [5]. Therefore, advances in technology to help orthopedic surgeons overcome these obstacles have become a focal point of investigation. Robotic-arm-assisted surgery was developed to increase the precision and accuracy of bone cuts and component alignment in hopes to improve patient satisfaction and functional outcomes [8]. RATKA has been shown to improve component alignment in a consistent and reproducible manner when compared to manual techniques [8,9]. However, a surgeon's experience with RATKA may be limited by concerns about increased operative times and decreased efficiency. Longer operative times require more anesthesia for patients and may lead to increased operating costs [10]. Despite these perceived disadvantages, Kayani et al. reported a learning curve of only 7 cases for an arthroplasty-trained orthopedic surgeon, and operative times may even further decrease after 6 months [11,12]. Importantly, these studies investigated only arthroplasty-fellowship-trained surgeons experienced with robotic-assisted surgery. The benefits of implementing RATKA may be clear for an arthroplasty surgeon, but it is difficult to define if there is an applicable advantage of RATKA to a general orthopedic practice.

The goal of this study was to investigate the learning curve of RATKA for a generalist orthopedic surgeon by analyzing two general practice orthopedic surgeons in a community setting. We hypothesize that the benefits of RATKA are not limited to only fellowship-trained arthroplasty surgeons. Knowledge of this expected learning curve may encourage more general orthopedic surgeons to use this innovative technology.

Material and methods

A retrospective analysis of robotic TKAs and manual TKAs, performed by two non-fellowship-trained orthopedic surgeons, was conducted. All TKAs were performed during a 13-month period, from January 2019 to January 2020. Institution review board approval was obtained before data collection. All TKAs were primary and unilateral. A total of 120 RATKAs and 40 manual TKAs were reviewed. Data for each surgeon's first 60 RATKAs and 20 manual TKAs performed after the initiation of RATKA were collected. For each individual surgeon, the RATKA cohort was divided into 3 consecutive cohorts of 20 patients. Cohort 1 comprised the first 20 RATKAs, cohort 2 was the second set of 20 RATKAs, and cohort 3 was the third set of 20 RATKAs. A fourth cohort consisted of a surgeon's 20 consecutive manual TKAs performed after the first RATKA by each individual surgeon. The surgeons chose to perform manual TKAs during times when the Stryker Robotic Arm System (Mako, Ft. Lauderdale, FL) was unavailable because of scheduling or manufacturer maintenance. Surgeon 2 specifically chose to perform manual TKAs on patients who had a previous contralateral manual TKA. For each surgeon, the operative times were compared for each RATKA cohort, then each RATKA cohort was individually compared with the manual TKA cohort. Cohorts were then grouped together for both surgeons and compared in a similar fashion.

Both surgeons are non-fellowship-trained, general practice orthopedists who operate at a nonacademic community hospital. These surgeons work daily with orthopedic surgical residents. Surgeon 1 had been in practice for 16 years, with an average annual TKA volume of 145 primary TKAs per year. Surgeon 2 had been in practice for 36 years, with an average annual TKA volume of 200

Table 1
Patient demographics.

	Robotic-assisted cases		Manual cases		P value
Total number of patients	120		40		
Age, mean (SD), range	66.1 (8.6)	43-83	70.0 (8.5)	47-83	0.0151
Gender (male), no. %	50	41.67%	12	30.00%	0.1896
BMI, mean (SD), range	33.5 (6.3)	18-47	32.8 (7.3)	18-46	0.5549

BMI, body mass index; SD, standard deviation.

TKAs per year. The Stryker Robotic Arm System was used for all RATKAs, and all patients underwent a preoperative computerized tomography scan for templating. Both surgeons received two 2-hour robotic training sessions. The first session consisted of the product specialists familiarizing the surgeons with the equipment, and the second session consisted of cadaveric practice. One surgeon and his surgical technologist visited a nearby hospital to observe surgeons using the Stryker Robotic Arm System. Each surgical technologist and the orthopedic surgical coordinator participated in an additional 2 hours of training on how to assist in operating with the robotic arm. All TKAs were performed with a tourniquet, standard medial parapatellar approach, and Stryker Triathlon cruciate retaining knee implants. Every patient had cemented tibial, femoral, and patellar components. Inclusion criteria included patients undergoing a primary, unilateral RATKA with symptomatic osteoarthritis who had failed extensive conservative measures. Exclusion criteria included revision surgery, uncemented implants, patients with prior hardware, and patients who underwent bilateral TKA or another procedure under one anesthesia event. The operative time, gender, age, and body mass index were collected for each patient. The primary outcome was operative time, which was defined as the time from skin incision to skin closure. Secondary outcomes included incidences of deep vein thrombosis, superficial or deep infection, readmission, or revision surgery within the 90-day postoperative period.

We reported the operative times as mean, median, and range. Mean operative times were compared using analysis of variance for three group comparisons and Student's t-tests for between-group comparisons. When it was determined that variances for the comparisons of the operative times were unequal, the Welch-Satterthwaite t-test was used. All tests were 2-sided with a criterion for statistical significance at a P value less than 0.05. All the analyses were performed by SAS 9.4 (SAS Institute, Cary, NC).

Results

Patient demographics were compared between robotic-assisted cases and manual cases (Table 1). There was a statistically significant difference in age, with patients undergoing manual TKA being older than patients undergoing RATKA (mean 70.0 vs 66.1 years, P = .0151). There were no differences between groups with regard to gender and body mass index.

Surgeon 1

Mean operative times for surgeon 1 for the manual cohort and three sequential robotic-assisted cohorts were 46.9, 59.1, 53.2, and

Table 2
Operative time comparison between robotic-assisted cases, surgeon 1.

	RATKA cases 1-20, mean (range)	RATKA cases 21-40, mean (range)	RATKA cases 41-60, mean (range)	P value
Total N	20	20	20	
Time (min)	59.1 (43-77)	53.2 (36-76)	53.3 (41-70)	.0703

Table 3
Operative time comparison between robotic-assisted and manual cases, surgeon 1.

	RATKA cases 1-20, mean (range)	RATKA cases 21-40, mean (range)	RATKA cases 41-60, mean (range)	MTKA, mean (range)
Total N	20	20	20	20
Time (min)	59.1 (43-77)	53.2 (36-76)	53.3 (41-70)	46.9 (34-60)
P value	<0.0001	0.0196	0.0104	

MTKA, manual total knee arthroplasty.

53.3 minutes, respectively. Median operative times were 44.5, 58.5, 51, and 51.5 minutes, respectively. There was no statistically significant difference between the operative times for the three sequential robotic-assisted cohorts (Table 2), although there was a trend toward statistical significance and decreased operative times between cases 1-20 and the remaining cohorts. In addition, mean operative times were significantly longer for each of the robotic-assisted cohorts than those for the manual cohort (Table 3).

Surgeon 2

Mean operative times for surgeon 2 for the manual cohort and three sequential robotic-assisted cohorts were 61.0, 74.8, 65.3, and 58.1 minutes, respectively. Median operative times were 61.5, 73.5, 65, and 57.5 minutes, respectively. Mean operative times for the three robotic-assisted cohorts decreased sequentially, with a statistically significant difference between the groups ($P < .0001$). The mean operative time for the first robotic-assisted cohort was significantly longer than that for the manual cohort (74.8 vs 61.0 minutes, $P < .0001$) (Table 4). However, when compared with the manual cohort, there was no significant difference between mean operative times for the second robotic-assisted cohort (63.5 vs 61.0 minutes, $P = .1103$) or the third robotic cohort (58.1 vs 61.0 minutes, $P = .1785$) (Table 5).

Surgeons 1 and 2 combined

Mean operative times for the combined surgeons manual and three robotic-assisted cohorts were 53.9, 67.0, 59.3, and 55.7 minutes, respectively. The mean operative time for the first robotic-assisted cohort was significantly greater than that for the second and third robotic cohorts ($P < .0001$). The mean operative time for the second robotic-assisted cohort was not statistically different compared with that for the third robotic cohort. When compared with the manual cohort, there was a significant difference between operative times for the first robotic cohort (67.0 vs 53.9 minutes, $P < .0001$) and the second robotic cohort (59.3 vs 53.9 minutes, $P = .0267$) (Table 6). However, there was no significant difference between operative times for the third robotic cohort and the manual cohort (55.7 vs 53.9 minutes, $P = .3870$) (Table 7).

Secondary outcomes

Among all patients, there were no incidences of deep vein thrombosis or prosthetic joint infection within the 90-day

Table 5
Operative time comparison between robotic-assisted and manual cases, surgeon 2.

	RATKA cases 1-20, mean (range)	RATKA cases 21-40, mean (range)	RATKA cases 41-60, mean (range)	MTKA, mean (range)
Total N	20	20	20	20
Time (min)	74.8 (59-96)	65.3 (51-85)	58.1 (50-70)	61 (47 -85)
P value	<0.0001	0.1103	0.1785	

MTKA, manual total knee arthroplasty.

postoperative period. Early adverse outcomes in patients who underwent RATKA included one patient who experienced cellulitis on the operative leg and required oral antibiotics, one patient who was readmitted for acute kidney injury, one patient who was readmitted for congestive heart failure exacerbation, and two patients who underwent manipulation under anesthesia for decreased knee range of motion.

Discussion

Given that 20% of patients are unsatisfied with their outcomes after TKA, surgeons have continually searched for methods to improve surgical outcomes. Robotic-assisted TKA provides improved preoperative planning and allows the surgeon to select the desired implant position and alignment before making an incision. An intraoperative robotic arm helps the surgeon make precise bone resections, which can decrease iatrogenic bone loss and periarticular soft-tissue injury compared with conventional TKAs [12,13]. The current literature on the learning curve of RATKA has only investigated arthroplasty-trained surgeons and reports that they can achieve their baseline surgical proficiency within a few months or after a few cases [11,12,14,15].

Kayani et al. prospectively looked at operative times in manual and robotic TKAs performed by a surgeon who previously only had cadaveric experience with RATKA [11]. In their study, a sharp decline in operative times was demonstrated after the seventh case [11]. It was also noted that there was no learning curve for implant accuracy and complication rates, indicating immediate improvement in operative accuracy without additional risk to the patient [8]. Sodhi et al. further explored the learning curve of RATKA using operative time as a marker of surgical proficiency [13]. They reviewed operative times in two high-volume arthroplasty surgeons and found that mean operative times in the first 20 robotic cases increased compared with each surgeon's mean time for manual TKAs. The authors reported that after the initial learning phase, operative times with RATKA were comparable to those with manual TKA, which is similar to the findings of our study. Koulalis et al. retrospectively reviewed the first 100 RATKAs at their institution and demonstrated that within 20 cases, they were able to achieve operative times within 5 minutes of their manual TKA [16].

Despite the potential advantages of robotic-assisted technology, implementation of this new surgical technology by a non-fellowship-trained surgeon is challenging given the potential for increased operative times and heightened levels of anxiety among

Table 4
Operative time comparison between robotic-assisted cases, surgeon 2.

	RATKA cases 1-20, mean (range)	RATKA cases 21-40, mean (range)	RATKA cases 41-60, mean (range)	*P* value
Total N	20	20	20	
Time (min)	74.8 (59-96)	65.3 (51-85)	58.1 (50-70)	<.0001

Table 6
Operative time comparison between robotic-assisted cases, surgeons combined.

	RATKA cases 1-20, mean (range)	RATKA cases 21-40, mean (range)	RATKA cases 41-60, mean (range)	*P* value
Total N	40	40	40	
Time (min)	67.0 (43-96)	59.3 (36-85)	55.7 (41-70)	<.0001

Table 7
Operative time comparison between robotic-assisted and manual cases, surgeons combined.

	RATKA cases 1-20, mean (range)	RATKA cases 21-40, mean (range)	RATKA cases 41-60, mean (range)	MTKA, mean (range)
Total N	40	40	40	40
Time (min)	67.0 (43-96)	59.3 (36-85)	55.7 (41-70)	53.9 (34-85)
P value	<0.0001	0.0267	0.3870	

MTKA, manual total knee arthroplasty.

the surgical team during the initial learning phase. Similar to all types of surgery, a learning curve must be met before surgeons can anticipate the ease of use to be similar to that of traditional manual cases [13]. The purpose of this study was to assess this learning curve among non-fellowship-trained surgeons for RATKA. Although robotic-assisted operative times for each surgeon were initially longer than those with their manual cases, when the two surgeon's robotic cohorts were combined, creating a more generalizable cohort, operative times in the last cohort were similar to manual operative times as seen in Figure 1.
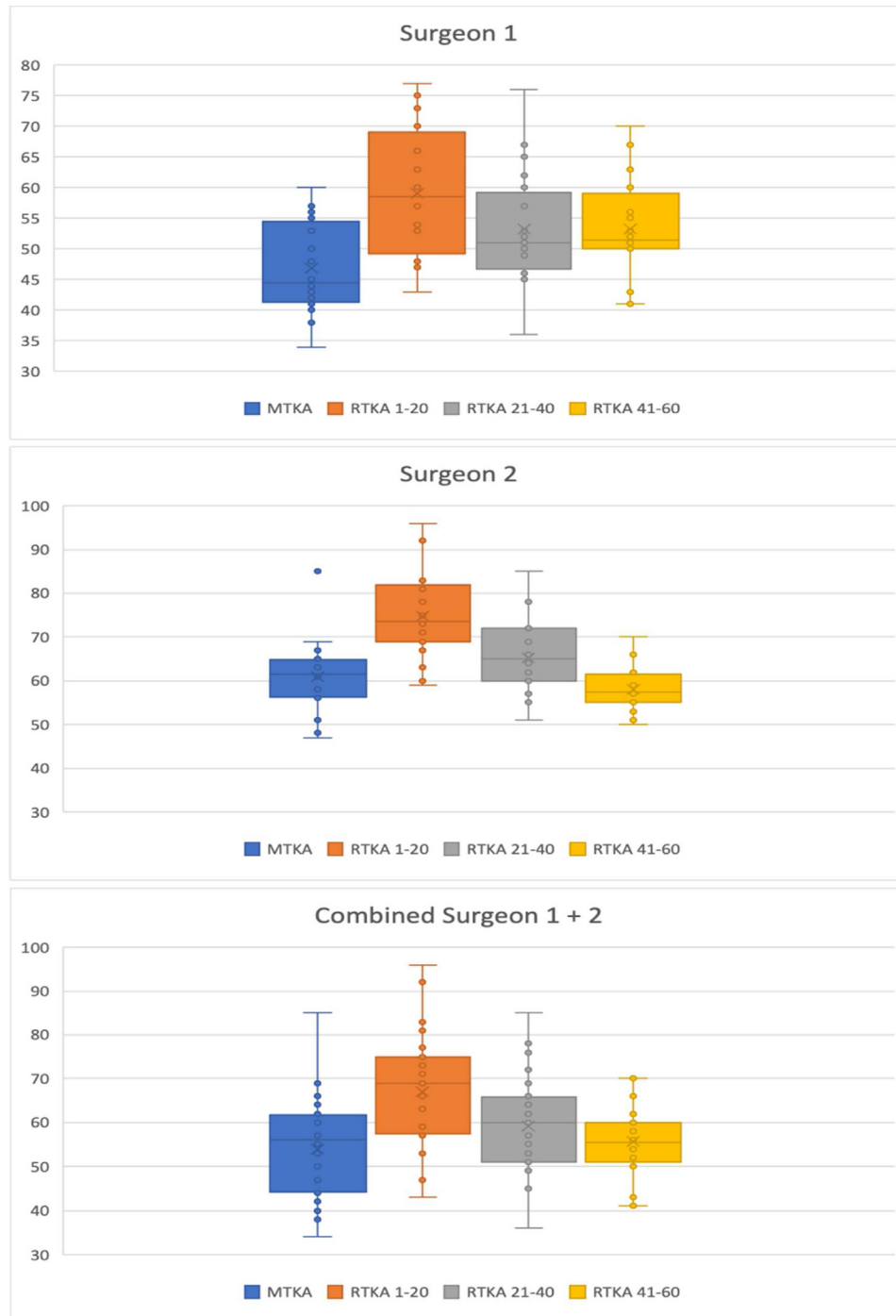

Figure 1. Bar graphs demonstrating the operative times in minutes for manual TKA (MTKA) and the first 60 robotic-assisted TKA (RTKA) of each individual surgeon and then the combined surgeon cohort.

The average operative time for RATKA was under 1 hour within the initial twenty cases for surgeon 1 and within the second cohort of cases for surgeon 2. When both the surgeons' cases were combined, the average operative time for RATKA within 21-40 cases was under 1 hour, and within 5.4 minutes of the average operative time for manual TKA. There was no statistical difference between the combined surgeon's third RATKA cohort and manual TKA. This study, therefore, demonstrates that the learning curve for RATKA in a non-fellowship-trained orthopedist can occur within the first 40 cases. In other words, a general orthopedic surgeon in a community hospital should be able to adequately perform robotic-assisted surgery in a similar timeframe to their conventional TKA within their first 40 RATKAs.

A few limitations to this study are that our patient population was not randomized but chosen sequentially. This allowed us to track changes in operative times and document the learning curve with the use of robotic assistance. We also did not analyze the severity of deformities between groups. While we recognize that a difference in angular deformities may be a confounding variable, the lack of any outliers in the operative times suggests that all patients had similar preoperative deformities. Furthermore, this study only analyzed the experience of two surgeons and categorized their learning curve based on operative times. The fact is that each surgeon's annual TKA volume >140 cases per year may limit the study's generalizability to the lower-volume general orthopedist. However, to the best of our knowledge, this is the first study performed at a community hospital setting where there are many general practice orthopedic surgeons. Future studies should focus on general orthopedists with lower surgical volumes, which would allow a more comprehensive definition of the learning curve for implementing robotic assistance in the community hospital setting.

Conclusions

While the advent of robotic-assisted TKA has become an attractive option for orthopedic surgeons, one disadvantage of new technology is the associated learning curve and potential for increased operative times. However, studies investigating this dilemma have only been performed by fellowship-trained arthroplasty surgeons. Our study demonstrates that the use of robotics for the general orthopedist is achievable and attainable. With a learning curve of approximately 40 cases, operative times for robotic-assisted TKA can become time neutral compared with a surgeon's manual TKA. RATKA should not be looked at as a daunting task for the general orthopedist but should be seen as an asset in those looking to implement robotic assistance in their practice.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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