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Original Research

Improved Efficiency and Intraoperative Planning With 1 Robot-Assisted Total Knee Arthroplasty System

Dalton L. Braathen, BS, Cameron Wallace, MD, Ian M. Clapp, MD, MS, Brenna E. Blackburn, PhD, Christopher L. Peters, MD, Michael J. Archibeck, MD*

Department of Orthopaedics, University of Utah, Salt Lake City, UT, USA

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Background: Robotic-assisted total knee arthroplasty (rTKA) has garnered significant interest for its potential to enhance surgical precision and accuracy. However, the adoption of such systems poses concerns, including longer operative times and learning curves, potentially reducing efficiency. This study aimed to evaluate the learning curve associated with the Robotic Surgical Assistant (ROSA) system for rTKA.

Methods: This retrospective review analyzed the first 75 ROSA rTKA procedures performed by each of 2 fellowship-trained arthroplasty surgeons (150 total procedures) at a high-volume institution. Time stamps within the robotic software were recorded for each case, along with tourniquet time. Statistical analyses included descriptive statistics, *t*-tests, and multilevel regression.

Results: Comparison of each surgeon's first 20 and last 20 cases revealed significant decreases in tourniquet time (61.4-56.7 minutes; $P = .0417$) and planning time (13.49-6.68 minutes; $P = .0078$). Landmark femur and tibia times remained stable ($P = .6542$ and $P = .9440$). Knee state evaluation time showed a trend of reduction from 9.22 to 7.33 minutes ($P = .1335$), and resection time from 13.66 to 12.92 minutes ($P = .4372$). Regression analysis indicated significant reductions in tourniquet time ($\beta = -0.11$; $P = .0089$) and planning time ($\beta = -0.08$; $P = .0064$).

Conclusions: This study demonstrates that execution of ROSA rTKA becomes more efficient over the first 75 cases. The greatest improvement with experience is the time spent on the planning panel, the cognitive portion of the procedure. These data provide surgeons with the confidence that the technical portions of the case are quick to learn and guide industry to focus on teaching effective adjustments on the planning panel.

Introduction

Increasing public interest in robotic-assisted total knee arthroplasty (rTKA) is shaping patients' expectations and perceptions when seeking treatment for knee osteoarthritis [1]. However, introducing a new system into the operating room (OR) can be challenging and potentially disrupt workflow. rTKA has been shown to require extended learning curves and longer OR times [2,3]. In general, rTKA outcomes and complication rates have been comparable to conventional total knee arthroplasty (TKA) causing debate on whether the cost is justified [4–7].

Robotics is a general term that encompasses different operating systems with different knee balancing methods, resection techniques, and image dependency. The main advantage of robotic surgery over manual TKA is the reduction of postoperative alignment outliers, improved gap balancing, and increased reproducibility of biomechanics [6,8]. These benefits have continued to improve in accuracy with newer generation models [9].

The Robotic Surgical Assistant (ROSA) Knee System (Zimmer Biomet, Warsaw, USA) was developed by Zimmer Biomet in collaboration with MedTech and approved by the Food and Drug Administration in 2021. Research is limited to small series and has shown ROSA to improve accuracy and precision of knee alignment when compared to conventional methods [10–12]. Early outcome

* Corresponding author. Department of Orthopaedics, University of Utah, 590 Wakara Way, Salt Lake City, UT 84108, USA. Tel.: +1 801 587 5410.
E-mail address: michael.archibeck@hsc.utah.edu

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data are comparative with other navigation systems [13]. However, one study has reported an increased benefit associated with the ROSA system involving less postoperative pain and greater range of motion at 1 year when compared to imageless navigated TKA [14]. ROSA, classified as a passive robot that can be used image-based or imageless, uses soft tissue laxity measurements and preresection adjustments to reduce the need for soft tissue releases and improve final balance. It uses a robotic surgical arm to position and hold cutting guides for bone resection and provides intraoperative feedback to optimize cuts based on the soft tissue envelope. Two previous studies identified a range within 5-15 cases required to get familiar with the ROSA protocol [15,16]. In 2022, Kenanidis et al looked at 100 cases and determined they achieved ROSA OR time neutrality after 73 cases compared to their own manual TKA [17]. Beyond this, ROSA implementation literature is limited.

The aim of the study was to assess a high-volume institution's implementation of a robot-assisted TKA system by evaluating each step in the process of performing an rTKA. We hypothesized that the cumulative experience of the surgical team would lead to an increase in intraoperative efficiency.

Material and methods

Patient population

Our retrospective review included the first 75 rTKA procedures performed by each of the 2 fellowship-trained arthroplasty surgeons (150 total procedures) at a high-volume institution. Inclusion criteria comprised patients undergoing primary TKA. Robotic procedures were identified using Current Procedural Terminology codes and verified using data from the ROSA (Zimmer Biomet, Warsaw, IN, USA) hard drives. This study was approved by the local institutional review board.

Surgical protocol

Surgeons A and B transitioned from a measured resection technique to using the ROSA robotic system for all cases in their surgical practice. The ROSA system was configured to follow the same workflow as the previous technique to maintain consistency in surgical processes. Both participating surgeons underwent a Zimmer Biomet Institute course and cadaveric practice workshop. The same group of physician assistants, anesthesiologists, nurses, and the same industry representative were involved during the study period. All procedures were performed by a trainee (fellow/resident) and/or physician assistant as a surgical assistant.

During anesthesia induction, the surgical team set up and preliminarily positioned the robotic device. The initial surgical aim was to execute a functional alignment approach within the confines of deformity limits. After bony and soft tissue registration, the anticipated bone cuts were adjusted to reduce the need for soft tissue releases [18,19]. All ROSA cases in this study used imageless ROSA. Zimmer Persona total knee components were used in all cases. A pneumatic thigh tourniquet was used in all cases.

Perioperative variables

Time stamps of specific steps were retrieved from local hard drives on ROSA and are reflective of time spent in the interface panels throughout the surgery. The ROSA time stamps are defined as follows:

- Set-up time: The duration of preparation. The timer starts from the moment the ROSA system is draped and positioned for surgery until the subsequent step is initiated.
- Knee evaluation time: The duration spent on the ROSA evaluation screen. This includes the time spent during soft tissue laxity registration in extension and flexion. The timer for knee evaluation continues to track even if the surgeon returns to review or modify previous evaluations until the final evaluation is saved.
- Landmark time: The interval from the moment the surgeon accesses the femur or tibia landmarking page to the completion of landmark registration for the respective bone.
- Planning time: The duration spent on the ROSA planning screen. This includes the period dedicated to preoperative planning, including adjustments in component positioning (coronal, axial, and sagittal plane adjustments to accommodate the soft tissues). The timer for planning time continues to accumulate even if the surgeon revisits the planning screen post-cuts to adjust or review the plan.
- Femoral and tibial cut time: This variable measures the time from when the robotic arm begins to move toward initiating cuts or enters collaborative mode until the completion of the cuts and subsequent removal of pins.

Clinical and operative notes were used to obtain patient data including age, body mass index, gender, and tourniquet time. Tourniquet time is defined as the total inflation time required in an rTKA procedure.

Statistical analysis

For each time metric, the first 20 cases for each surgeon were compared to the last 20 cases for each surgeon using *t*-tests. Multilevel regression models, to account for multiple surgeons, were performed to analyze changes in each time metric over the course of each surgeon's first 75 cases. Statistical significance was set at 0.05. All statistical analysis was performed using Statistical Analysis Software 9.4 (SAS Institute, Cary, NC).

A total of 150 procedures were included (the first 75 cases performed by surgeon A and the first 75 cases by surgeon B). Overall, 56% (N = 84) of the patients were female (Table 1). The patients had an average age of 66.2 years (standard deviation = 9.6) and average body mass index of 31.5 kg/m^2 (standard deviation = 6.2).

Results

A comparison of the institution's first 20 (cases 1-20) and last 20 (cases 130-150) ROSA cases revealed a significant decrease in tourniquet time and planning time (Table 2). Tourniquet time significantly decreased from a mean of 61.4 minutes to 56.7 minutes ($P = .0417$). Planning time also showed a statistically significant reduction, decreasing from 13.49 minutes to 6.68 minutes ($P = .0078$). In contrast, landmark femur and tibia times remained stable, with no significant changes observed ($P = .6542$ and $P = .9440$, respectively). Knee state evaluation time decreased from 9.22 minutes to 7.33 minutes, although this change was not

Table 1
Demographics of patients.

Demographics		N (%)
Sex		
Female		84 (56.0)
Male		66 (44.0)
	Mean (standard deviation)	
Age	66.2 (9.6)	
BMI	31.5 (6.2)	

BMI, body mass index.

Table 2
Comparison of the specific operative step durations of early (1–20) and late (131-150) rTKA cases using the ROSA complete knee system.

Operative step	First 20 cases	Last 20 cases	*P* value
	Mean (standard deviation)	Mean (standard deviation)	
Tourniquet time (min)	61.4 (8.9)	56.7 (8.6)	.0417
Times from ROSA			
Landmark femur (min)	2.73 (0.60)	2.67 (0.76)	.6542
Landmark tibia (min)	1.03 (0.38)	1.04 (0.36)	.9440
Knee state evaluation (min)	9.22 (6.12)	7.33 (5.00)	.1335
Planning (min)	13.49 (10.16)	6.68 (4.60)	.0078
Surgery (cuts) (min)	13.66 (3.52)	12.92 (4.85)	.4372

rTKA, robotic-assisted total knee arthroplasty.

statistically significant ($P = .1335$). Finally, surgery (cuts) time showed a slight reduction from 13.66 minutes to 12.92 minutes, but this was not statistically significant ($P = .4372$). These results indicate that certain aspects of the procedure, such as tourniquet and planning times, improve significantly with experience, while others remain consistent (Fig. 1).

A regression analysis was conducted to account for each individual surgeon and to illustrate procedural efficiency on a per-case basis (Table 3). Tourniquet time showed a significant reduction with increased case experience ($\beta = -0.11$; $P = .0089$). Planning time also demonstrated a significant improvement, decreasing with increased case experience ($\beta = -0.08$; $P = .0064$). In contrast, the times for femur and tibia landmarking remained stable, with no significant changes observed. The knee state evaluation time showed a trend toward improvement, but this change was not statistically significant ($\beta = -0.04$; $P = .0806$). Similarly, surgery (cuts) time did not show a significant association with increased experience.

Discussion

The time and case numbers required to overcome the learning curve associated with rTKA vary among different robotic systems. Our study aimed to evaluate the efficiency gains over time with the ROSA system, focusing on specific procedural steps. The most pertinent findings of this study were (1) overall surgical time, expressed as tourniquet time, significantly improved with experience; (2) the “planning” step showed the most significant

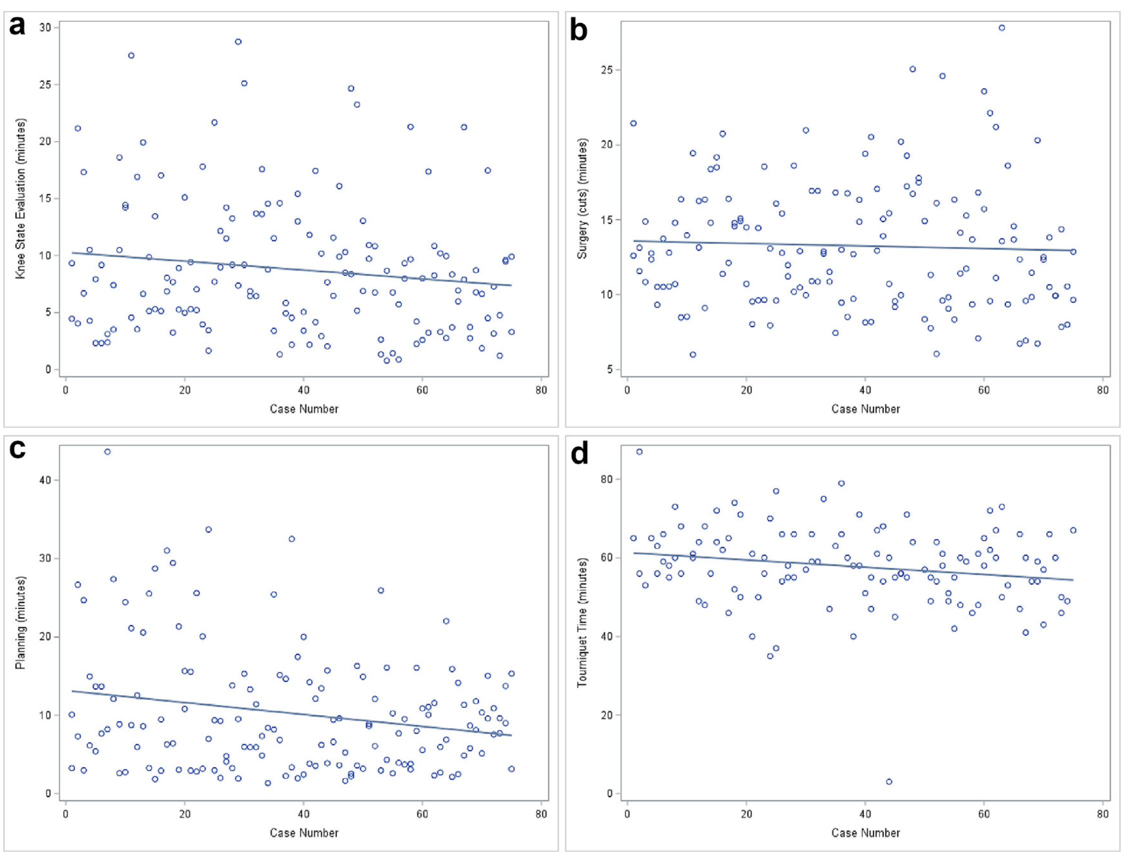

Figure 1. Scatter plots illustrating an institution’s case count versus individual surgical steps of rTKA using the ROSA system for (a) knee state evaluation time, (b) surgery time, (c) planning time, and (d) tourniquet time. rTKA, robotic-assisted total knee arthroplasty.

Table 3
Multivariate analysis of specific operative time points during rTKA using the ROSA system, controlling for individual surgeons and operative time.

Operative step	Beta coefficient (standard error)	*P* value
Tourniquet time (min)	−0.11 (0.04)	.0089
Times from ROSA		
Landmark femur (min)	0.000 (0.003)	.9450
Landmark tibia (min)	0.001 (0.002)	.6697
Knee state evaluation (min)	−0.04 (0.02)	.0806
Planning (min)	−0.08 (0.03)	.0064
Surgery (cuts) (min)	−0.008 (0.015)	.5733

rTKA, robotic-assisted total knee arthroplasty.

improvement with experience; and (3) the technical steps of resections (cuts) and landmarking were quickly learned and remained relatively stable.

The knee planning stage is arguably the most cognitively demanding step, involving decisions on resection thickness, resection angle, and component size for both the tibia and femur. Surgeons use predictive values of final gaps and alignments provided by the interface to guide these decisions [20]. In contrast, tasks such as evaluating ligament laxity, assessing range of motion, landmarking bones, and performing surgical cuts are more streamlined and require less cognitive effort, making them easier to learn.

Previous studies evaluating ROSA rTKA have identified various learning periods. The earliest study, Vanlommel et al performed 90 ROSA rTKA and identified an initial improved efficiency around the completion of 6-11 cases [15]. Bolam et al followed finding a similar improved efficiency after a mean case experience of 8.7 cases [16]. Both articles reported no significant difference when compared to their conventional operative times but did not report the actual data. The only study to illustrate time neutrality was Kenanidis et al after 70 cases of ROSA experience looking at a surgeon's first 100 cases [17]. Our findings suggest the improved efficiency of an institution accumulates with experience, and that time neutrality, if achieved, might result from improvement within the knee planning stage.

Previous robotic systems such as the Mako (Stryker, Fort Lauderdale, Florida), Food and Drug Administration−approved in 2015, have been well studied. Learning curves generated in previous studies have a large range of approximately 7-43 cases with early studies favoring smaller curves [3,21−23]. It is possible that early ROSA studies with lower learning curves may have included surgeons involved with system design and therefore had more familiarity with the system. As more research is generated, the learning curve may expand. Emphasis should be placed on improvement of cognitive steps such as knee planning to optimize efficiency.

The potential limitations of this study include the inherent limitations of retrospective design. While we attempted to control multiple factors by involving only 1 surgical group at a high-volume institution, this may also limit the generalizability of our findings. Furthermore, it should be noted that one of the participating surgeons had limited and intermittent exposure to ROSA at a prior institution which biased the data to a null hypothesis. Additionally, cases were not consecutive for 1 of the participating surgeons as there was a time period where he transitioned to manual TKA and then back to ROSA rTKA for all cases during the study period. However, our study included a substantial number of cases providing robust data on the implementation within the OR. Our surgical team was consistent throughout the dates of operation. Further research is needed to evaluate the learning curve of ROSA in diverse clinical environments and to explore the potential for long-term efficiency gains beyond the initial 75 cases.

Conclusions

Our study provides valuable insights into the learning curve associated with the use of the ROSA robotic system in TKA. The findings indicate that surgeons starting to use ROSA for rTKA can expect a reduction in time over the first 75 cases, with the most significant improvements observed in the cognitive portions of the procedure, particularly the planning panel. This suggests that while technical aspects of the surgery are quickly mastered, the greatest potential for time reduction lies in the cognitive steps. These results provide surgeons with the confidence that they can efficiently adopt ROSA for rTKA. Additionally, the data highlight the importance for industry and educators to focus on teaching effective and common adjustments on the planning panel to further enhance procedural efficiency. Further research is warranted to determine the extent of efficiency gains beyond 75 cases.

Conflicts of interest

Michael Archibeck is a paid consultant for Zimmer Biomet and received research support from Zimmer Biomet as a Principal Investigator. Brenna Blackburn is a board member of AAHKS. Christopher L. Peters received royalties from Zimmer Biomet; is a paid consultant for Zimmer Biomet; is an unpaid consultant for OrthoGrid; holds stock or stock options in OrthoGrid and CoNextions; received research support from Zimmer Biomet as a Principal Investigator; and is a board member of the Knee Society. All other authors declare no potential conflicts of interest.

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CRediT authorship contribution statement

Dalton L. Braathen: Writing − original draft, Methodology, Data curation. **Cameron Wallace:** Writing − review & editing, Writing − original draft, Data curation. **Ian M. Clapp:** Writing − review & editing, Data curation. **Brenna E. Blackburn:** Writing − review & editing, Methodology, Formal analysis, Data curation. **Christopher L. Peters:** Writing − review & editing, Supervision, Conceptualization. **Michael J. Archibeck:** Writing − review & editing, Supervision, Methodology, Data curation, Conceptualization.

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