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Research Article

Robotic-Assisted Operative Experience Effect on Robotic Learning Curve for Total Knee Arthroplasty

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Abstract

Background: As more robotic technologies are introduced into orthopedics, it is important for surgeons to understand the learning curve for switching robotic systems. Thus, adoption time was investigated for a robot-trained surgeon conducting robotic-assisted total knee arthroplasty (raTKA).

Materials and Methods: Data were collected retrospectively from twenty patients undergoing robotic-assisted primary TKA (raTKA). Operating Room (OR) time, robot time, and implant size difference were investigated. Cumulative sum analysis was performed in order to determine the inflection point at which efficiency was reached.

Results: The study found that prior robotic experience shortened the transition time to a new robotic TKA system. Additionally, while efficiency was reached for each parameter, the time to do so varied. For robot time, efficiency was reached after 4 cases, 6 cases for implant size difference, and 12 cases for overall OR time.

Conclusion: In the study, it was found that for a high-volume arthroplasty surgeon with prior robotic experience, the learning curve for a new robotic TKA system was relatively small. It was also found that efficiency was reached with fewer cases for robot-specific time compared to general OR time.

***Keywords:** Robotic Adoption; raTKA; Transition Time; Learning Curve; OR Time*

Abbreviations

raTKA: Robotic-Assisted Total Knee Arthroplasty; CUSUM: Cumulative Sum

Introduction

In 1988, the first robotic-assisted total knee arthroplasty (raTKA) was performed in the United Kingdom [12]. Since then, its utilization has increased exponentially to meet the demand for a procedure that has improved patients' lives through increased precision, patient-reported outcomes, hospital quality metrics, and cost efficacy [5,6,8]. Recently, the American Joint Replacement Registry 10th annual report documented a six-fold increase in robotic-assisted knee replacements since 2017, aided in part by the public's interest in undergoing knee replacement via the robotic approach [2,11]. Projections suggest that by 2030, raTKA will constitute 50% of all TKAs [4]. While conventional TKA offers continuous efficacy and efficiency with improved prosthesis systems, its limitations lie in facing complex TKAs, often leading to patient dissatisfaction [3,7]. As a result, surgeons adopting robotic systems often witness improved patient outcomes with decreased operative times as robotic-assisted volume increases [9]. With the orthopedics industry shifting from conventional to robotic-assisted surgeries, the emergence of different and novel robotic systems has not ceased to advance, with five currently available systems as of 2022 [14].

While this innovation in approach to knee replacements shows potential benefits, adding new technology may result in a period of learning for both the surgeon and the surgical team. The literature review showcased several papers demonstrating learning curves for surgeons with various baseline characteristics: non-fellowship-trained, fellowship-trained, and high-volume arthroplasty surgeons. Ali., *et al*. [1] demonstrated that approximately 40 cases are required to reach optimal operative times in a non-fellowship-trained surgeon compared with a surgeon's conventional TKA [1]. However, an arthroplasty-trained orthopedic surgeon still required 7 cases to significantly reduce operative times [8]. Similarly, in a study evaluating the long-term learning curve of raTKA, Marchand., *et al*. [10] found that operative time continued to decrease at six months and 1 year [10]. A systematic review and meta-analysis comparing the associated learning curve in 16 studies further showed that the number of cases for efficient operative time was between 7 and 11 cases [15].

While several studies have investigated robotic adoption learning curves, to date, none have discussed the effect of previous robotic training or robotic usage on learning curves. This study aims to examine the effect of previous robotic experience on the learning curve when adapting to a new robotic system for a high-volume, arthroplasty-trained surgeon. Such a study is paramount given the robotic-assisted joint replacement landscape has grown significantly in the last several years, with every major implant company now offering robotic assistance. This has introduced the opportunity for surgeons to select different vendors without losing the advantages that technology brings. The arrival of many different robotic-assisted options certainly allows for many advantages, increasing surgeon choice and competition between device companies, potentially bringing down cost while driving technology advancement. However, it is important to understand how changing vendors and the accompanying robotic assistant will affect the surgeon's workflow and operative time.

Considering this topic has not yet been explored in the current literature, it will provide objective data and allow orthopedic surgeons to switch robotic systems confidently. To evaluate the learning curve in this new setting, our investigation focused on measuring (1) total operative time, (2) total robot time in the surgical field, and (3) implant size difference between robot template vs. surgeon selection.

Materials and Methods

Data were collected retrospectively from twenty patients undergoing robotic-assisted primary TKA (raTKA). Consecutive raTKAs performed by a single high-volume surgeon from January to May 2021 at Montefiore Hutchinson Campus were examined in chronological order for analysis. The surgeon had previous experience with Stryker MAKO (Mawah, NJ, USA), but had recently adopted the Zimmer ROSA system (Warsaw, IN, USA).

Both robotic systems are primarily used for total knee, total hip, and partial knee arthroplasty. However, the former is CT-based while the latter, newly adopted robotic system operates using X-rays and/or an image-free basis. Inclusion criteria consisted of the first twenty primary TKA cases using the new robotic system. Patients' ages in the study ranged from 39 to 83 years old and variable BMIs ranged from 21.68 to 52.73. Knee laterality was equally distributed with 10 patients undergoing right knee TKA and 10 left knee TKA, and only one patient had a history of previous knee surgery. Demographic information for the patients is provided below.

Primary outcomes of interest were OR time, robot time and implant size difference (ISD). OR time refers to the total time spent in the operating room, robot time is defined as the time when the ROSA robot entered and exited the field after surgical exposure, and ISD is the total implant size difference between the robot-selected versus surgeon-selected template. The twenty cases were listed in sequential order and data for each variable were reviewed. Cumulative sum (CUSUM) analysis was performed to extract the minimum number of cases needed to reach efficiency for each parameter.

	Cohort n=20
Age	
Mean ± STDEV	63 ± 10
Range	39-83
BMI	
Mean ± STDEV	32.3 ± 7
Range	21.7-52.7
Gender	
Male	3 (15%)
Female	17 (85%)
Laterality	
Right	10 (50%)
Left	10 (50%)

Table 1: *Demographics information for the patients in the study.*

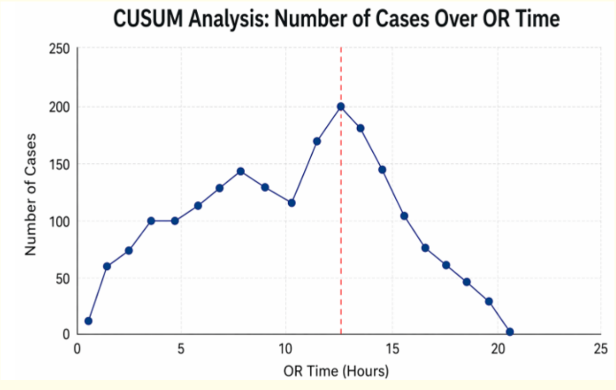
CUSUM is defined as the sum of the deviation from the target (mean of all data points). X_i =Operation-Time for each case, μ=Mean Operation-time (1).

$$CUSUM_{OpTime_n} = \sum_{k=1}^{n} x_i - \mu$$

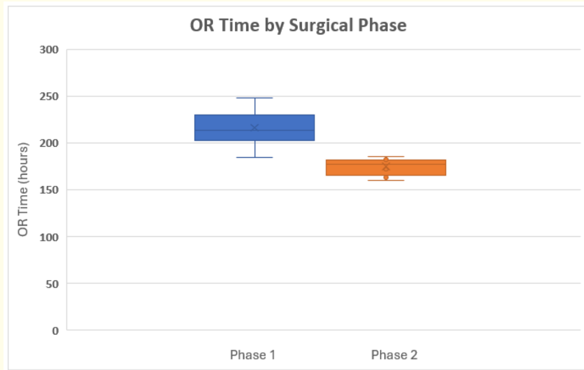
A specific number of cases, defined by the maximum inflection point, were defined for the OR time, robot time, and ISD, respectively. Cases prior to the inflection point were classified as a learning curve or Phase 1 group, and cases thereafter as an efficient phase or Phase 2 group. Wilcoxon-Sum Rank analysis was performed to detect any significant differences in the three parameters between these two groups. The study was approved by the Institutional Review Board (IRB).

Results and Discussion

The minimum number of total knee arthroplasty (TKA) cases needed to reach efficient OR time, robot time, and implant size difference in a raTKA experienced surgeon operating with a new robotic system varies. Graph 1a shows the number of TKA cases in relation to the amount of time spent in the operating room (OR time) to reach efficiency. CUSUM analysis of the total OR time shows an inflection point (red dashed line) after 12 cases. Cases within the first 12 TKAs or learning curve (Phase 1 group) were then compared to the 8 cases in the efficient phase (Phase 2 group) in graph 1b. The average time for phase 1 was 216 ± 19 minutes compared to 175 ± 9 minutes in phase 2 ($p < 0.05$).

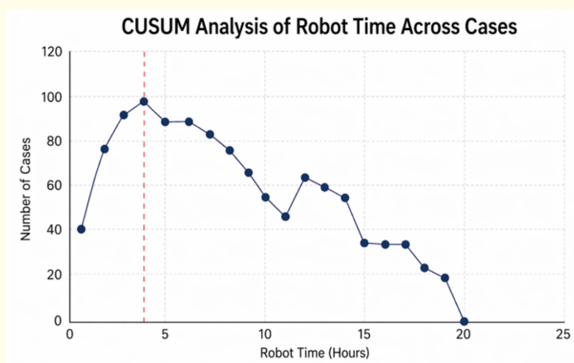


Graph 1a: *Number of Cases vs. OR time with inflection point per CUSUM analysis marked as red dashed line.*

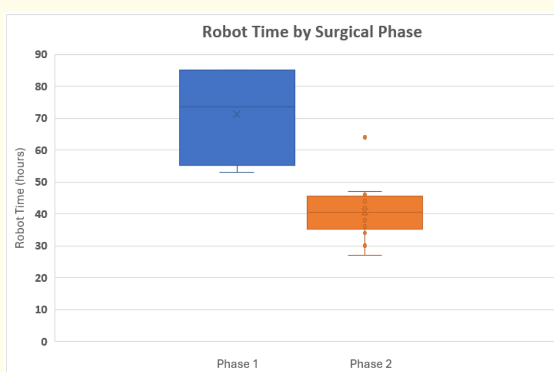


Graph 1b: *OR Time (hours) for phase 1 and phase 2.*

Notably, when measuring robot time, the number of cases to reach efficiency is reduced when compared to that of the OR time. Graph 2a shows that the minimum number of cases to reach inflection is 4, and a decline in the robot time follows thereafter. The average robot time in the first 4 cases (Phase 1 group) is 71 ± 16 minutes. The average robot time in the remaining 16 cases, or Phase 2, is markedly decreased to 41 ± 8 minutes ($p < 0.05$) as shown by graph 2b.

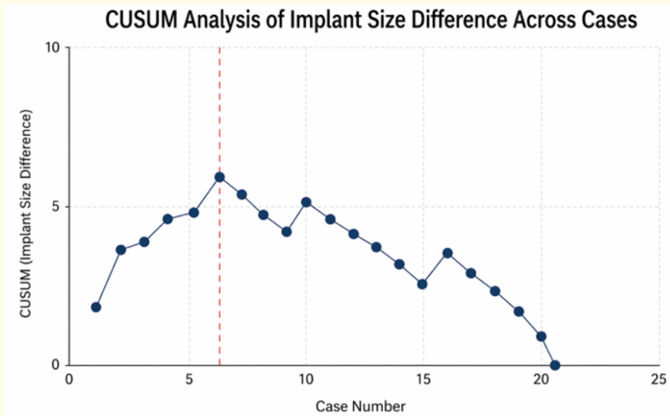


Graph 2a: *Number of cases vs. robot time with inflection point per CUSUM analysis marked as a red dashed line.*

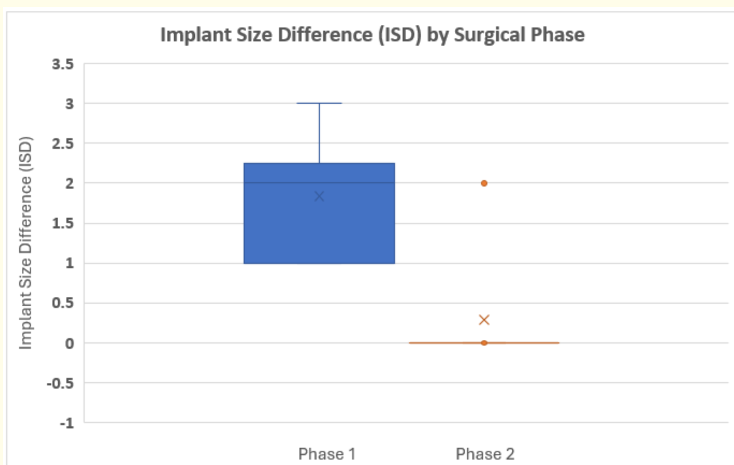


Graph 2b: *Robot time (hours) for phase 1 and phase 2.*

The difference in implant size shows a similar trend to that of robot time. Graph 3a demonstrates that the inflection point occurs after 6 cases, as per CUSUM analysis. Graph 3b shows the learning curve (Phase 1 group) with an average implant size difference of 2 ± 0.7, compared to 0 ± 0.7 in the efficient phase (Phase 2 group) ($p < 0.05$).



Graph 3a: *Number of cases and implant size difference (ISD) with inflection point per CUSUM analysis marked as a red dashed line.*



Graph 3b: *Implant size difference (ISD) for phase 1 and phase 2.*

From the study, it was found that prior robotic experience shortened the transition time to a new robotic TKA system. Additionally, while efficiency was reached for each parameter, the time to do so varied. For robot time, efficiency was reached after 4 cases, 6 cases for implant size difference, and 12 cases for overall OR time.

While related, robot time and OR time are distinct. Robot time demonstrates the surgeon's interaction with the new robotic device. However, OR time also reflects other dynamics, including anesthesia, other surgical staff, devices, etc. Overall OR time likely presented with the greatest number of cases before efficiency because time spent in the OR involves more than the surgeon's efforts with the robot.

Thus, the longer OR time does not necessarily display surgical issues but a more general adaptation. The data also display that prior robotic surgical experience can help adapt to other robotic systems. This could be due to the surgeon's prior experience that allowed them to better understand robotic mechanisms. As seen from the ISD findings, a greater level of consistency between the surgeon and robot was seen - possibly displaying a greater level of cohesion. The findings suggest improved trust of the surgeon for the robot and understanding for the technology. Similar findings were reported by Schopper., *et al*. [13] which found that experience amongst surgeons decreased the learning curve for robotics [13].

Previous studies looking into robotic adoption for raTKA mostly investigated learning curves for first-time robot users; however, this study detailed the transition of a robot-technology-fluent surgeon to a new system. Similarly, Kayani., *et al*. [8] reported the learning curve for robotic integration of 7 cases while other studies reported that achieving time neutrality requires around 15 - 20 cases [8,10]. This study demonstrated that previous surgical experience can significantly decrease the adaptation time.

The results of the study could provide valuable information for surgeons and medical centers interested in switching robotic systems. The information can be helpful for institutions in planning, credentialing, and resource allocation. Thus, surgeons anticipating switching surgical robotic systems do not necessarily need to anticipate long adoption times. Since vendors may increase charges for their equipment, an understanding of the learning curves for transitioning could help institutions effectively cost plan and adapt to changes.

While the study displays valuable information for robotic adoption for surgeons, there are various limitations to the study. The study involved 20 cases and was constrained to one surgeon and institution. Additionally, since the surgeon involved in the study was an arthroplasty-trained surgeon who had prior experience with robotic systems, the results of the study may not be generalized to surgeons who do not meet those same criteria. In the study, while the impact on the surgeon was tested, neither patient data nor clinical outcomes were gathered. Thus, there is limited knowledge on the study subjects and success of the surgeries.

Conclusion

In the study, it was found that for a high-volume arthroplasty surgeon with prior robotic experience, the learning curve for a new robotic TKA system was relatively small. It was also found that efficiency was reached with fewer cases for robot-specific time compared to general OR time.

Conflict of Interest

None.

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