

Evaluation of the Safe Implementation and Proficiency of Four-Port Solo Robot-Assisted Total Laparoscopic Hysterectomy Based on Uterine Size

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Abstract

Objective

To evaluate proficiency in four-port robot-assisted total laparoscopic hysterectomy (RA-TLH) performed without an assistant, based on the surgeon's number of procedures, console time, and weight of retrieved tissue.

Materials and Methods

The 486 cases of RA-TLH were classified by retrieved tissue weight into Group S (< 250 g), Group M ($\geq$ 250 g but < 500 g), Group L ($\geq$ 500 g but < 750 g), Group H ($\geq$ 750 g but < 1,000 g), and Group G ($\geq$ 1,000g but < 3000g). Proficiency was assessed based on the number of cases performed and the cumulative sum (CUSUM). This study is a single-center retrospective case–control study.

Results

Group A (surgeons with $\leq$ 20 cases) demonstrated a significantly longer console time than Group B (21–40 cases) only for cases with a retrieved weight of $\leq$ 500 g. Groups B, C ($\geq$ 41 cases), and D (experienced surgeons) showed no significant differences. A significant difference in blood loss was observed only between Groups A and C within the M group. The learning curves of the four novice surgeons exhibited a biphasic pattern, with turning points occurring at the 15th, 17th, 18th, and 37th cases.

Conclusion

We estimate that proficiency in this procedure is achieved following approximately 20 cases involving uteri weighing $\leq$ 500 g. Furthermore, the results suggest that skilled surgeons can perform even high-difficulty cases involving uteri weighing $\geq$ 1,000 g in a minimally invasive and safe manner.

Introduction

Total hysterectomy represents the standard treatment for benign uterine conditions. Laparoscopic total hysterectomy has recently gained widespread adoption as the standard minimally invasive procedure as it causes less postoperative pain, a shorter hospital stay, and an earlier return to daily activities than open surgery [1, 2]. However, in cases involving a giant uterus, the operative space within the pelvis is substantially constrained, and the difficulty of laparoscopic surgery increases owing to limited visual access, reduced uterine mobility, and restricted forceps manipulation [3, 4].

Robot-assisted surgery provides benefits not achieved in conventional laparoscopic surgery, including a three-dimensional field of view, high degrees of freedom for forceps manipulation, and superior

ergonomics [5, 6]. However, in cases involving a giant uterus, the close proximity between the camera and uterus or collisions between robotic arms, which can restrict surgical field exposure, may limit even robot-assisted surgery.

One solution is to move the camera port position higher, as is performed in laparoscopic surgery. However, in cases of a giant uterus, limitations exist regarding how high the camera can be positioned. However, using the previously reported four-port technique [7], adequate distance can be maintained between the ports, and viewing the fibroids from a slightly lateral angle becomes possible as the camera is not positioned in the midline. Furthermore, the lateral aspects of the uterus can be more effectively managed by adopting port hopping and utilizing the strong force of the robotic forceps to sufficiently retract the enlarged uterus laterally, thereby facilitating surgery with greater freedom of movement.

Regarding four-port robot-assisted hysterectomy, we have previously reported that combining the four-port technique, which does not use an assistant port, with port hopping facilitates “solo surgery,” a characteristic of robotic surgery, while maintaining safety, thereby reducing manpower and healthcare costs [8].

Therefore, this study aimed to evaluate the true surgical skill of the surgeon using the four-port technique through a learning curve. In laparoscopic and robotic surgery, the skill level of the assistant frequently impacts surgical outcomes. However, as the four-port technique does not necessitate an assistant, it enables a more direct assessment of the surgeon’s skill. Furthermore, uterine weight can impact the surgeon’s skill. Therefore, this study also evaluated surgeons on the basis of the weight of retrieved tissue and investigated indicators for safely performing surgery.

Materials and Methods

Between July 2020 and October 2025, our hospital performed 493 total hysterectomies for benign uterine tumors after obtaining adequate informed consent. As we generally did not impose size restrictions, 486 cases (98.6%) were robot-assisted total laparoscopic hysterectomies (RA-TLHs), and 7 cases (1.4%) were total abdominal hysterectomies (TAH). However, this study excluded TAH cases as they did not align with the study objectives.

With the exception of one case (7,000 g), the weight of the retrieved tissue in the RA-TLH group was $\leq$ 3,000 g in all other cases; therefore, this analysis focused on cases weighing 3,000 g or less and classified them into five groups. The study population comprised 174, 162, 79, 30, and 40 cases with retrieved tissue weights of < 250 g (small group [SG]), ≥ 250 g but < 500 g (medium group [MG]), ≥ 500 g but < 750 g (large group [LG]), ≥ 750 g but $< 1,000$ g (huge group [HG]), and $\geq 1,000$ g (giant group [GG]), respectively (Fig. 1).

We compared patient characteristics, including age, body mass index (BMI), and minimum abdominal width (MAW; defined as the narrowest abdominal width on routine preoperative anteroposterior plain abdominal X-rays), as well as perioperative surgical outcomes, including operative time, console time

(CT), preparation time, closure time, time to retrieve resected tissue, weight of retrieved tissue, blood loss, conversion to open surgery, length of hospital stay, and complications, across the five groups. Regarding the SG, we focused on high-difficulty cases identified through preoperative evaluation, including physical examination, imaging studies, and medical history.

Surgery was performed under general anesthesia with the patient in the lithotomy position at a head-down angle of 25°–30° using a levitator. A Belles needle was inserted through the umbilicus; after securing the surgical field at a 10-mmHg pneumoperitoneum pressure, ports were created. The surgical robot employed was the Da Vinci X or Xi (Intuitive Surgical, Sunnyvale, CA, USA), with a side-docking approach rolling in from the patient's left side. RA-TLH was performed as a four-port surgery without using an assist port in all cases. Briefly, an 8-mm Da Vinci endoscopic port was first created using the optical method, horizontally 4 cm to the right of the point 4 cm directly above the navel. The remaining three 8-mm Da Vinci ports were arranged in a straight line, spaced 8 cm apart from each other [7]. Considering forceps manipulation, we employed a proprietary "port-hopping" technique [7]. The forceps used encompassed ProGrasp™ Forceps, Monopolar Curved Scissors, Maryland Bipolar Forceps, and Large SutureCut™ Needle Driver.

Two highly experienced robotic surgeons (skilled robotic surgeons) with over five years of robotic surgery experience and more than 100 cases of RA-TLH and six surgeons (novice robotic surgeons) with no prior robotic surgery experience performed these surgeries.

Among these six surgeons, the learning curves for the control time were evaluated using cumulative sum (CUSUM) analysis [9, 10] for the four surgeons (surgeons 1–4) who had experience with ≥ 60 RA-TLH cases. In the CUSUM analysis, the CUSUM value for the operating time of the first case was calculated by determining the difference between its CT and the average CT of all cases. For cases following the first one, the CUSUM value from the previous case was added to the difference from the average CT. For example, for the second case, the CUSUM value from the first case was added to the difference between the CT of the second case and the average CT of all cases. Calculating this process through the final case yielded a continuous graph. Furthermore, to evaluate the surgeon's proficiency, cases of RA-TLH were classified into four groups on the basis of the surgeon's experience: 1–20 cases (group A), 21–40 cases (group B), ≥ 41 cases (group C), and skilled robotic surgeons (group D). Subsequently, surgical outcomes were compared across the tissue retrieval groups within each of these groups.

Furthermore, regarding retrieval methods, this study investigated three approaches: conventional transvaginal (TV) retrieval, transvaginal retrieval using a wound retractor (WR), and retrieval via a small incision (a 3-cm horizontal incision 1 cm above the pubic bone [SI]) [11].

Regarding statistical analyses, comparisons between two groups were performed using Student's t-test; significant differences among three groups were assessed using Tukey's HSD test or the Games–Howell test. A p-value of < 0.05 was considered statistically significant. All statistical analyses were performed using the Statistical Package for the Social Sciences (version 29; SPSS 29).

The Institutional Ethics Committee of Tokyo International Ohori Hospital approved this study (approval number: 2025-0003).

Results

The number of cases by retrieved tissue weight, from the lightest to the heaviest, was 174 cases (SG), 162 cases (MG), 79 cases (LG), 30 cases (HG), and 40 cases (GG); the number of cases decreased as the weight increased. An analysis of the background characteristics of the five groups revealed no significant differences between the groups in terms of age, height, or BMI, except that the GG exhibited a significantly higher mean age (MAW) than the SG and HG (Table 1). The mean weights of the retrieved uterus were 162 (55–249), 348 (250–499), 613 (501–747), 869 (752–990), and 1,457 (1,005–2,766) g in the SG, MG, LG, HG, and GG, respectively. The GG demonstrated significantly longer mean operative time (272 min), CT (174 min), closure time (18 min), and retrieval time (55 min), as well as a significantly higher blood loss (333 mL), than the SG, MG, LG, and HG; however, no significant differences in length of hospital stay were observed among the groups (Table 1). One case (2.5%) in the GG received allogeneic blood transfusion.

In the analysis of tissue retrieval, the SG encompassed almost entirely of TV retrieval, with the proportion decreasing as the retrieval weight increased; the GG demonstrated no TV retrieval. The MG, LG, and HG most frequently employed WR (50%–60%); however, its use was lower in GG (30%), with 70% of cases involving SI retrieval (Supplementary Table 1). In the GG, the mean weight of tissue retrieved via WR was 1,264 (1,005–1,756) g, the retrieval time was 55 (26–97) min, and blood loss was 413 (2–535) mL. By contrast, the mean weight of tissue retrieved via SI was 1,539 (1,029–2,766) g, the retrieval time was 55 (10–161) min, and blood loss was 152 (10–1,247) mL.

In the analysis of proficiency, the learning curve based on CT for the four surgeons revealed two distinct phases (phase 1, characterized by a positive slope, and phase 2, characterized by a negative slope). The turning points occurred at the 37th, 17th, 18th, and 15th case for surgeons 1, 2, 3, and 4, respectively (Fig. 2). Furthermore, surgeon 1 was inexperienced in laparoscopic surgery, whereas surgeon 4 was a certified laparoscopic surgeon.

Regarding the number of cases in each group classified by the number of cases performed and arranged from the least to the most number of cases, Groups A, B, C, and D had 102, 80, 124, and 179 cases, respectively. In the comparison of CT among surgeons within each tissue recovery group, in Groups S and M (tissue recovery weight, < 500 g), a significant reduction in CT was observed between Groups A and B (classified by surgeon experience); however, Groups B and C exhibited no significant difference. Regarding tissue recovery weights of ≥ 500 g, Groups A, B, and C demonstrated no significant differences. Compared with Group D (skilled surgeons), Group A showed a significant difference in the weight range of ≥ 250 g but < 750 g; however, no significant differences were observed in any of the other weight groups. Groups B and C exhibited no significant differences from Group D in any of the weight groups (Table 2).

Conversely, regarding tissue recovery weights of < 250 g, the proportion of high-difficulty cases was the highest and lowest in Groups D (46.9%) and A (4.5%), respectively (Supplementary Table 2).

Similarly, regarding blood loss, a significant difference was observed only in Group M (recovered weight of ≥ 250 g but < 500 g) compared with Group A, which had a small number of cases, and Group C, which comprised experienced surgeons; however, no significant differences were observed between the other experience groups in any of the recovered weight groups (Supplementary Table 3).

Furthermore, when cases of RA-TLH were divided into three groups (Group A, ≤ 20 cases; Groups B and C, ≥ 20 cases; and Group D, skilled surgeons) and compared the proportion of cases in each weight group within each group, it was observed that in Group S (recovery weight, ≤ 250 g), Groups A (43.1%) and B + C (38.7%) had a higher proportion of cases than Group D (28.5%); conversely, in Group G (recovery weight, $\geq 1,000$ g), Group D (11.7%) had the highest proportion of cases (Table 3). In Group G, skilled surgeons performed 21 of 40 cases (52.5%).

Regarding complications, the overall incidence was 2.9% ($n = 14/485$ cases). Group G exhibited the highest incidence rate by recovered weight at 7.5% ($n = 3/40$ cases; 1 of whom required blood transfusion), whereas the other groups demonstrated incidence rates ranging from 0% to 3.8%. However, most complications were classified as Clavien–Dindo Class II or lower, encompassing 10 and 3 cases of intra-pelvic infection and intra-abdominal hematoma, respectively. The only case classified as Class III or higher was in Group G (Class IIIb), which required robotic hemostasis on the third postoperative day owing to intra-abdominal hemorrhage (Table 4). Conversely, no cases required conversion to open surgery.

Discussion

We here investigated the safety and proficiency of four-port RA-TLH without an assistant, focusing on uterine weight and surgeon experience. Specifically, we clarified two points: (1) the safety of this procedure for giant uteri and (2) the learning curve considering the surgeon's experience and uterine weight.

In RA-TLHs, operating time, blood loss, and the rate of conversion to open surgery increase when uterine weight exceeds 750 g [12]. Conversely, recently, an increasing number of studies have revealed that RA-TLH can be safely performed even on giant uteri weighing > 1,000 g [13–15]. The present study suggested that in Group G (uterine weight, $\geq 1,000$ g), CT and blood loss significantly increased, indicating that giant uteri present a higher surgical difficulty. However, as no increase in hospital stay or severe complications was observed and that no cases of conversion to open surgery were noted, it was concluded that with appropriate case selection and surgeon assignment, the procedure can be safely performed on giant uteri while maintaining its minimally invasive nature.

Several studies on the learning curve for robot-assisted surgery have been conducted; Seamon et al. and Lim et al. have reported that the learning curve flattens after approximately 20–40 cases [16–18].

Similarly, in this study, the “turning point,” a proficiency indicator, occurred between 15 and 37 cases, aligning with previous studies. Conversely, a distinctive feature of this study is that it centered on solo surgery, which is not assistant-dependent. As this surgical technique reduces the influence of the assistant’s role in exposing the surgical field and retracting tissues, we believe that we evaluated a learning curve that more directly reflects the surgeon’s skills.

Furthermore, when proficiency was evaluated by uterine weight, for uteri weighing < 500 g, Group A (with an experience of ≤ 20 cases) exhibited a significantly longer CT than Group B (with an experience of > 20 cases); therefore, for uteri of this size, approximately 20 cases were considered a benchmark for proficiency. Conversely, for uteri weighing ≥ 500 g, the experience groups demonstrated no significant difference in CT. However, this finding does not indicate that even beginners can safely perform procedures on giant uteri. In this study, the proportion of cases performed by skilled surgeons increased as uterine weight increased; for uteri weighing $\geq 1,000$ g, skilled surgeons performed > 50% of the procedures, indicating the presence of a clear case-selection bias. Therefore, these results should be interpreted as outcomes obtained under conditions where appropriate case selection was performed. Furthermore, the presence of groups that demonstrated no difference in CT between novice and experienced surgeons for small uteri may be due to the assignment of high-difficulty cases, including those with severe adhesions, to experienced surgeons.

Bleeding volume was low, averaging ≤ 100 mL in all groups except for Group G ($\geq 1,000$ g); no significant differences were observed based on surgeon experience. This finding is believed to be because the expanded field of view and superior forceps maneuverability provided by robotic surgery enabled even novice surgeons to perform stable hemostasis. The results of this study aligned with previous reports [19, 20], suggesting that robot-assisted surgery contributes to decreased blood loss and accelerated postoperative recovery compared with laparoscopic surgery.

The incidence of perioperative complications in conventional RA-TLH has been reported to be 5%–10%, which is deemed comparable to that of laparoscopic surgery [21, 22]. In this study, the complication rate was low at 2.9%; even in the group with giant uteri weighing $\geq 1,000$ g, the rate was lower than that reported in previous studies [23, 24]. Furthermore, only one case (0.21%) was classified as Clavien–Dindo grade III or higher; no cases required conversion to open surgery. These findings suggest that this surgical technique is applicable to giant uteri without compromising safety, even as a solo surgery that does not necessitate an assistant.

In this procedure, no assistant port was used; we ensured sufficient distance between ports and adequate surgical field exposure even for giant uteri by combining the four-port configuration with the port-hopping technique. Furthermore, the use of the third arm facilitated the surgeon to independently perform stable traction and retraction, minimizing assistant-dependence. Moreover, as this procedure can be performed with one assistant, it can potentially contribute to savings in human resources and costs. Conversely, although some limitations regarding suction maneuvers and needle insertion/removal

were noted, these did not pose significant clinical difficulties due to the introduction of barbed sutures insertable through 8-mm ports and the use of the third arm.

The limitations of this study encompassed its retrospective single-center design and the nonrandomized case selection. In particular, exceedingly challenging cases, including those involving a macrosomic uterus or severe adhesions, were performed by highly skilled surgeons, introducing selection bias into the inter-surgeon comparison. Furthermore, this study did not examine difficulty factors other than uterine weight (e.g., fibroid location, uterine mobility, and the severity of endometriosis); future prospective studies that take these factors into account are warranted.

The most significant feature of this study is that it evaluated the learning curve in solo surgery, which does not rely on an assistant, while taking uterine weight, a measure of surgical difficulty, into account. Consequently, we believe that we have provided clinically useful indicators regarding the uterine size that novice surgeons should start with and the number of cases required for achieving proficiency.

Conclusion

Four-port solo RA-TLH, which does not require an assistant, yields safe and favorable perioperative outcomes, and early proficiency can be expected even among novice robotic surgeons. In particular, for cases with a retrieved uterine weight of < 500 g, approximately 20 cases were considered a benchmark for achieving proficiency. Conversely, in cases involving a massive uterus with a retrieved weight of $\geq$ 1,000 g, although CT, blood loss, and technical difficulty increased, the procedure could still be safely performed while maintaining its minimally invasive characteristics, without increasing the rate of conversion to open surgery or the incidence of serious complications, provided that appropriate case selection and surgeon assignment were implemented.

The significance of this study lies in its evaluation of the learning curve for uterine weight-based assistant-independent solo surgery and its proposal of safe implementation criteria.

Abbreviations

RA-TLH, robot-assisted total laparoscopic hysterectomy; TAH, total abdominal hysterectomy; BMI, body mass index; MAW, minimum abdominal width; CT, console time; CUSUM, cumulative sum; TV, transvaginal retrieval; WR, transvaginal retrieval using a wound retractor; SI, small incision retrieval

Declarations

Disclosure statement: The authors declare that they have no conflicts of interest and nothing to disclose

Author contributions:

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Hiroe Ito and Keiichi Isaka. The first draft of the manuscript was written by Hiroe Ito and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript

Ethical approval

The present study adhered to the ethical standards of the Declaration of Helsinki. Ethical approval for this study was obtained from the Ethics Committee of Tokyo International Ohori Hospital (Date 10/31/2025 /No 2025-0003).

Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

No assistance from AI or AI-assisted technologies was received in the creation of this manuscript.

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Tables

Tables 1 to 4 are available in the Supplementary Files section.

Figures

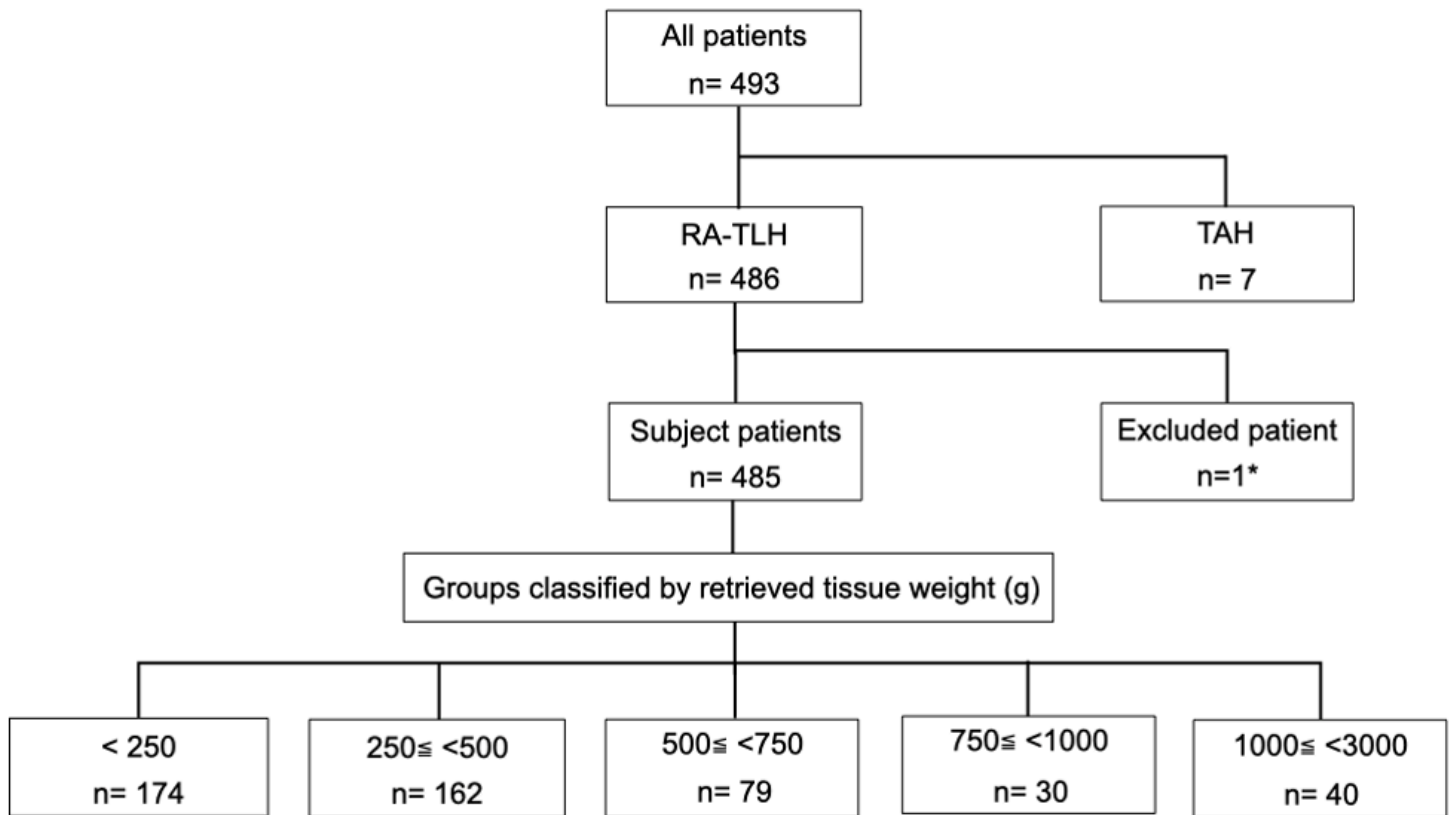


Figure 1

Flowchart for patients and surgical procedures in this study

RA-TLH: Robot-assisted total laparoscopic hysterectomy, TAH: Total abdominal hysterectomy, * This case was excluded because it was the only one in which the retrieved weight exceeded 3000g (7141 g).

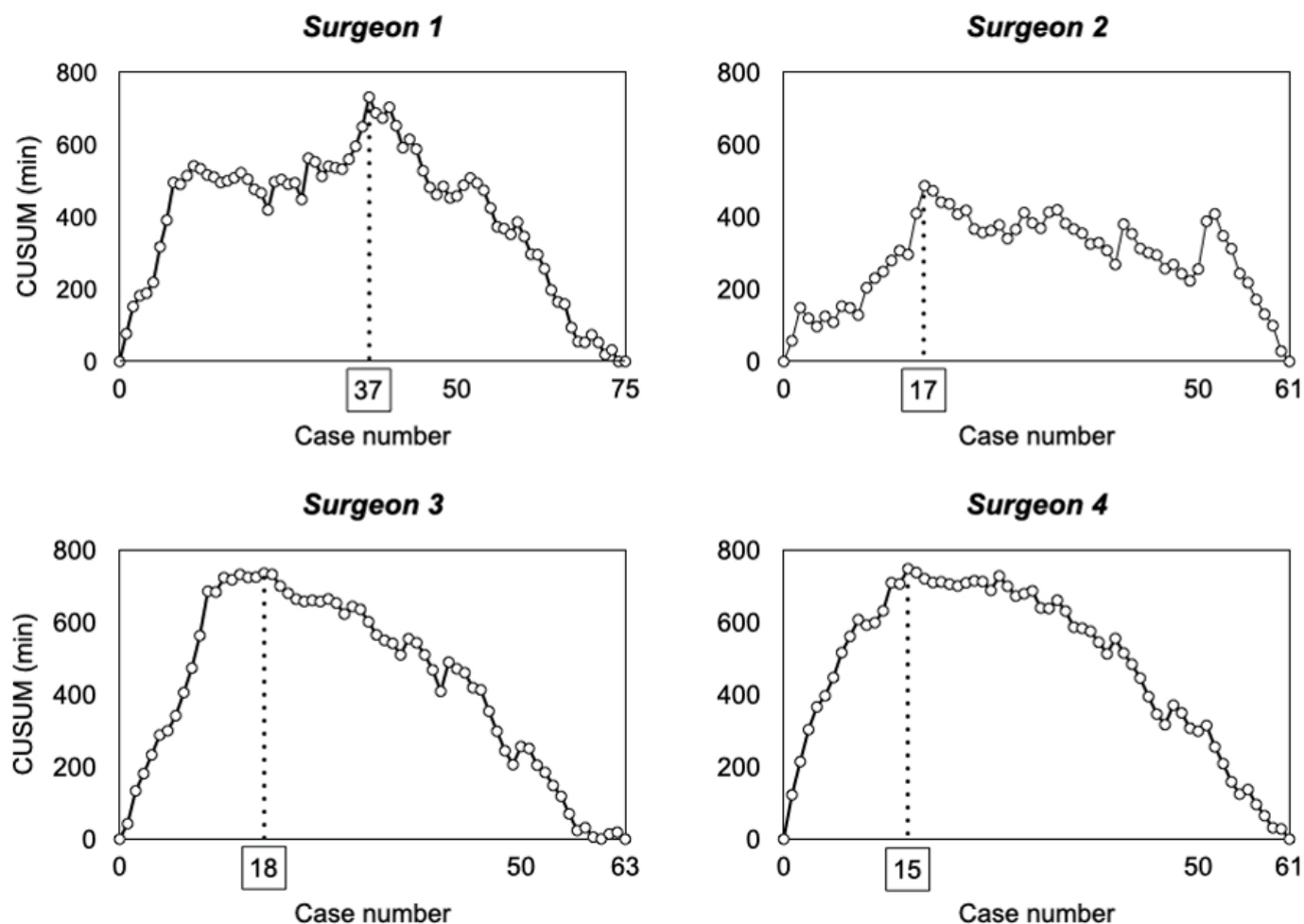


Figure 2

Learning curves and turning points for four surgeons

The cumulative sum (CUSUM) graph was created based on console time for each case number.

Supplementary Files

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