UNIVERSITE PARIS CITE / SORBONNE UNIVERSITE
U.F.R. Médecine

Année 2025

MEMOIRE
POUR LE DIPLÔME INTER-UNIVERSITAIRE
DE CHIRURGIE ROBOTIQUE

Présenté
le 30/06/2025
Par
Maria Stella CIPRIANI
Né le 15/07/1994 à Faenza

LEARNING CURVE IN ROBOTIC SURGERY FOR URETEROPELVIC JUNCTION OBSTRUCTION IN CHILDREN: HOW TO BEST DEFINE A RELIABLE LEARNING PROCESS

DIRECTEURS DU MÉMOIRE :
Le Professeur Girolamo MATTIOLI
Le Docteur Marcello CARLUCCI

Abstract

Introduction

Ureteropelvic junction obstruction (UPJO) is the most common indication for robotic surgery in pediatric urology. Early learning curve (LC) studies in children have focused on robot-assisted laparoscopic pyeloplasty (RALP), often using cumulative sum (CUSUM) analysis, especially for operative times.

Objective

To evaluate the LC of a pediatric urologist experienced in open and laparoscopic surgery performing RALP, using CUSUM analysis of both operative times and surgical outcomes.

Study Design

This single-centre prospective study included children who underwent RALP for UPJO between February 2021 and October 2024 using the da Vinci Xi® system. Exclusion criteria were previous UPJO surgery, major comorbidities, or loss to follow-up. Data collected included demographics, symptoms, imaging, operative times, and surgical outcomes. Additional variables included stent/drain use, conversions, hospital stay, and follow-up. CUSUM analysis was applied to total operative time (TOT), console operative time (COT), and a composite parameter (CP) combining TOT, complications, and success.

Results

Twenty-two patients were included. Mean age was 3.8 years (range 0.4–12.6) and mean weight 17.1 kg (6–43). Mean TOT was 158.1 minutes, and mean COT was 109.2 minutes. Four patients had Clavien-Dindo grade ≥3b urological complications. Mean follow-up was 11.6 months. CUSUM-TOT (Chart A) and CUSUM-COT (Chart D) curves revealed three phases: introductory (4 cases), proficiency (6 cases), and mastery (12 cases). The CUSUM-CP curve (Chart E), however, identified two phases: an introductory phase of 17 patients and a proficiency phase of 5.

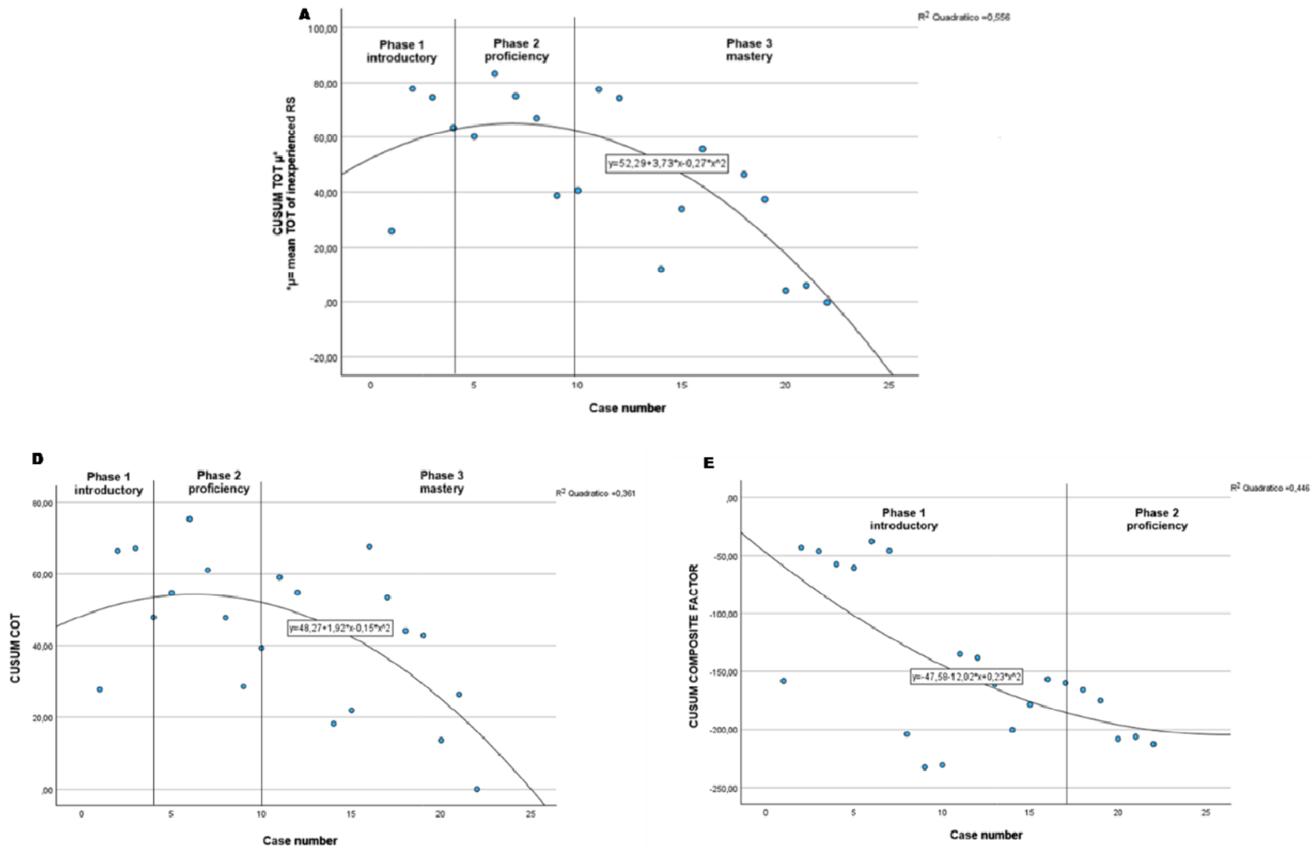
Discussion

CUSUM analysis of operative times may suggest early mastery, but including outcome-based parameters provides a more realistic reflection of clinical proficiency. Composite metrics revealed a longer LC than operative time alone, highlighting the influence of postoperative outcomes in assessing surgical competency. The study is limited by small sample size, short follow-up, and use of a non-validated composite score.

Conclusion

When based solely on operative times, the LC suggests early mastery; however, outcome-based CUSUM analysis shows proficiency only after 17 cases. These findings emphasize the need for standardized, multidimensional LC assessments in pediatric RALP to better capture the complexity of the learning process.

Abstract Figure



Title page

LEARNING CURVE IN ROBOTIC SURGERY FOR URETEROPELVIC JUNCTION OBSTRUCTION IN CHILDREN: HOW TO BEST DEFINE A RELIABLE LEARNING PROCESS

From the Pediatric Surgery Department of IRCCS, Istituto Giannina Gaslini, 16147 Genoa, Italy

Keywords RALP, UPJO, pyeloplasty, robotic surgery, learning curve, cusum

Corresponding author:

Maria Stella Cipriani, Pediatric Surgery Department, IRCCS, Istituto Giannina Gaslini, 16147, Genoa, Italy; DINOGMI, University of Genoa, Genoa, Italy +39 3342027882. Electronic address: mstellacipriani@gmail.com

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Manuscript

Introduction

Ureteropelvic junction obstruction (UPJO) is defined as an impairment in urine flow from the renal pelvis to the proximal ureter, leading to dilation of the collecting system and potential kidney damage. It has an overall incidence of 1 in 1 500 live births and is more common in males, with a 2:1 male-to-female ratio[1]. UPJO is most commonly detected through antenatal ultrasound (US) screening.

Over the past fifteen years, robotic-assisted laparoscopic pyeloplasty (RALP) has become increasingly widespread and, where available, is now the preferred surgical approach for treating UPJO in children. An exception is made for smaller children, for whom open pyeloplasty remains favourable due to shorter anesthesia duration and fewer spatial constraints for robotic instruments[2], [3].The gold standard technique continues to be the Anderson-Hynes dismembered pyeloplasty, first described in 1949[4].

The learning curve (LC) of robotic surgery (RS) has been extensively studied. While widely adopted in adult surgery, RS use in children is still evolving, with UPJO being the most common indication. Consequently, the first pediatric LC studies have focused on RALP[5]. In 2022 a systematic review reported the fifteen most relevant LC studies on RALP available at that moment, with only four utilizing the cumulative sum (CUSUM) method[6].

To date, six studies have reported on the LC of RALP using CUSUM analysis [7], [8], [9], [10], [11], [12], with all except Kassite et al. [10]focusing exclusively on operative times.

The aim of our prospective study is to evaluate the LC of RALP performed by a pediatric urologist already proficient in open and conventional minimally invasive surgery (MIS). We apply a rigorous methodology that examines not only operative times (console and total operative time) but also surgical outcomes, particularly urological complications and overall success.

Material and methods

All children (aged 0–18 years) diagnosed with UPJO who underwent RALP at our institution between February 2021 and October 2024, and were operated by the study-designated surgeon, were prospectively enrolled. The study was approved by the Regional Ethical Committee(reference number 579/2020-DB id 11005) and the informed consent was obtained by all patients prior to surgery.

Patients were excluded if they had major comorbidities, had previously undergone surgery for UPJO, or were lost to follow-up.

The recorded data included patient demographics, clinical details and diagnostic workup.As part of the preoperative evaluation, all patients underwent preoperative renal US and either MAG3 renal scan or functional magnetic resonance urography (fMRU) to evaluate UPJO and confirm surgical indication. This imaging modality provides information on split renal function, contrast accumulation patterns during the urographic phase, and detailed renal anatomy [13].

Intraoperativetimes, surgical details, intraoperative complications and need for conversion were collected.

Operative times were meticulously recorded and categorized into four intervals:

- Total Operative Time (TOT) – from skin incision to skin closure,
- Trocar Placement and Docking Time – from skin incision to the start of console use,
- Console Operative Time (COT) – duration of the surgeon’s active operation at the robotic console, and
- Dedocking and Skin Closure Time – from the end of console use to skin closure.

Postoperative data included: length of hospital stay, duration of catheterisation and peri-renal drainage,and postoperative complications graded more then 3b, according to Clavien-Dindo classification.

Postoperative follow-up included renal US prior to stent removal, and again within one to three months after stent removal. Subsequent US evaluations were performed at 6 months, 12 months, and annually thereafter. If the anteroposterior diameter (APD) increased compared to baseline, an fMRU was performed to assess for UPJO recurrence. Surgical success was defined as the resolution of UPJO at last follow-up, evidenced by either improvement in hydronephrosis on US or a favourable urographic phase on follow-up fMRU, without the need for redo pyeloplasty.

Surgery

The operating surgeon was a paediatric urologist with substantial experience in both open and conventional MIS and had undergone structured training in dry and wet laboratory environments. A senior consultant provided supervision and proctoring during the initial procedures to ensure adherence to surgical standards and patient safety.

All procedures were performed using the da Vinci Xi® Surgical System (Intuitive Surgical Inc., Sunnyvale, CA, USA). A transperitoneal dismembered pyeloplasty was carried out in all enrolled patients. The patient was placed in a 45° lateral decubitus position with the affected side elevated. Depending on patient size, three or four 8 mm robotic trocars were used. Pneumoperitoneum was established and maintained at a pressure of 10mmHg.

An Anderson-Hynes dismembered pyeloplasty was performed and anureteral stent placed in all cases.

Statistical analysis

Descriptive data are presented as means with standard deviation for continuous variables, and as absolute numbers with corresponding percentages for categorical variables.

The LC was evaluated using the CUSUM method. CUSUM analysis of a parameter varying during a learning phase is defined as:

CUSUM= $\sum_{n=1}^{\infty}(\mathrm{Xi}\ -\mu)$

where Xirepresents the individual patient's value for a given parameter, and μ denotes the reference mean.

This reference mean may be calculated from the study population or derived from values reported in the literature[6].

The parameters assessed using CUSUM charts included TOT and COT. To illustrate the sensitivity of CUSUM analysis to the choice of mean, CUSUM-TOT was plotted using three different reference means: the mean TOT of the study cohort and two alternative means obtained from published studies on RALP[14], [15].For the CUSUM-COT chart, only the cohort's mean COT was used, due to the absence of published meta-analytical data on this specific parameter.

Subsequently, we sought to develop a composite parameter (CP) that would reflect not only TOT, but also major urological complications and surgical failure, in order to observe how these additional clinical outcomes might influence the LC.

Major urological complications were classified as those with a Clavien-Dindo grade of ≥ 3b.

TheCP was calculated using the following formula:

CP= TOT x SF x CF

The Success Factor (SF) was assigned a value of 1 in cases without the need for redo pyeloplasty and with either improvement of hydronephrosis at US or a favourable urographic phase on follow-up fMRU. An SF of 0 was assigned when redo pyeloplasty was required. CF (Complication Factor) was defined as follows: a value of 1 in the absence of major urological complications; 1.3 if the patient required only ureteral stenting due to leakage or sub-stenosis; and 1.6 if reoperation was necessary due to anastomotic dehiscence or stenosis. While both of the latter scenarios correspond to Clavien-Dindo grade 3b complications, we considered it clinically meaningful to differentiate between them.

CUSUM charts were employed to assess whether distinct learning phases could be identified and characterised. The phases identified in the CUSUM-TOT and CUSUM-CP charts were compared using the Chi-square test. A *p*-value of less than 0.05 was considered statistically significant.

Results

A total of 24 patients met the inclusion criteria. One patient was excluded for not undergoing follow-up evaluations, and another was excluded due to anatomic variations—specifically, a back-rotated renal pelvis—that resulted in a prolonged operative time and a technically challenging RALP procedure.

Demographic and operative data are summarized in Table 1. The youngest patient was 4.8 months old and weighed 6 kg. The meanTOT was 158.1 minutes, and the mean COT was 109.2 minutes.

Postoperative complications of Clavien-Dindo grade ≥ 3b occurred in five patients. One patient developed segmental ileal necrosis due to evisceration through the drain site, requiring ileal resection. The first patient enrolled in the study required a redo open pyeloplasty due to anastomotic dehiscence. Another patient underwent redo RALP for recurrent obstruction. In two cases, ureteral stents were reinserted due to anastomotic leakage following premature removal of a Bracci stent.

Figure 1 illustrates the CUSUM analysis on Total Operative Time.

Chart A displays the CUSUM-TOT curve using the individual surgeon's mean TOT as the reference. By analysing the curve 3 distinct phases were identified:

- Phase 1 (introductory): the first 4 cases
- Phase 2 (proficiency): the following 6 cases, forming a plateau
- Phase 3 (mastery): the final 12 cases, in which the surgeon's performance rapidly improves, consistently surpassing his own average.

Chart B shows an introductory phase comprising 15 patients, which was necessary for the surgeon to reach the mean TOT reported in the literature by Ekin(namely 150 minutes) [14]. This is followed by a proficiency phase involving 7 patients. No mastery phase is observed when using this reference mean.

Chart C, on the other hand, displays only a mastery phase, as the surgeon's initial TOT was already below the mean TOT reported by Silay (173.1 minutes)[15], indicating superior performance from the outset.

Figure 2 compares Chart A with Chart D, the latter representing the CUSUM-COT curve using the operating surgeon's mean COT as the reference, due to the absence of meta-analytic data reporting a mean COT for RALP in the literature. The phases were defined consistently, each comprising the same number of patients: 4 in the introductory phase, 6 in the proficiency phase, and 12 in the mastery phase.

When patients are divided into three groups corresponding to the defined phases, neither the Trocar Placement and Docking Time nor the Dedocking and Skin Closure Time shows a statistically significant difference among the groups ($p > 0.05$).

The CUSUM-CP curve, based on the surgeon’s mean CP, showed a different trend compared to the other curves. It consisted of only two phases: an introductory phase involving 17 patients and a proficiency phase with 5 patients. The phase distribution in Chart E (CUSUM-CP) was statistically significantly different from that in Chart A, with a *p*-value < 0.001 (Figure 3).

Discussion

The aim of this study was to evaluate the LC of RALP performed by a pediatric urologist using the CUSUM method.

The superiority of RALP over laparoscopic pyeloplasty found agreement among most experts because RS compared to laparoscopy has a more ergonomic platform, high-resolution three-dimensional vision, a tremor filtering system with motion scaling, and instruments with articulation like that of the human wrist. Most of studies comparing the two approaches are retrospective. However, a 2020 randomised controlled trial by Silay et al. reported comparable success and complication rates between RALP and laparoscopic pyeloplasty. Notably, RALP had a shorter operative time but was associated with approximately four times higher costs [16].

Comparative analyses of the LCs for RALP and laparoscopic pyeloplasty have shown that RS allows for more rapid acquisition of technical proficiency. Moreover, skills acquired in one modality appear transferable to the other, suggesting mutual benefit between experiences in RALP and laparoscopic pyeloplasty [9], [17].

CUSUM is a statistical process control tool used to quantitative asses consecutive performances, it may detect trends that may otherwise be undetected due to natural data variability [7].

To our knowledge, six published studies have reported on the LC for RALP using CUSUM analysis[7], [8], [9], [10], [11], [12], with all except Kassite et al. focusing exclusively on operative times.Additional studies have evaluated the LC for trainees performing RALP[18], [19].

While some studies in the literature have suggested that the use of a dual console may positively influence the LC, these observations have been made in the context of other surgical procedures and not to RALP specifically[20].

Our cohort of 22 patients exhibited demographics and preoperative characteristics consistent with those reported in the literature.The mean TOT and COT were 158.1 and 109.2 minutes, respectively. Reported mean TOTs in previous LC studies vary widely, ranging from 142.2 to 232 minutes [7], [8], [9], [10], [12], while only Cundy et al [7] reported mean COT (167.8 minutes).
We report five distinct CUSUM charts.Figure 1 illustrates three charts based on TOT, highlighting how the shape of the CUSUM curve shifts depending on the reference mean used. The TOT, reflecting the activity of the entire surgical team, can be considered part of the team's overall LC, not solely that of the console surgeon.
Most prior studies employed the operating surgeon's own mean TOT, while Kassite et al. used a literature-derived value of 150 minutes[10].
These variations significantly impact the interpretation of the learning phases. This observation helped us better understand how the choice of reference values influences CUSUM analysis and may explain the discrepancies between previous studies. Currently, a standardized mean TOT for RALP is difficult to establish due to the absence of multicentre studies free from confounding factors such as surgeon experience and institutional practices. In our opinion, the CUSUM chart which better represent a LC is the one which use the mean of a specific parameter (e.g., TOT) derived from the population under investigation.
Figure 2shows the comparison between CUSUM-TOT and CUSUM-COT curves. Prior to the analysis, we hypothesized that COT would be the more appropriate parameter to assess the LC, as it more directly reflects the individual surgeon’s performance. However, COT may still be influenced by factors beyond the console surgeon’s control—for example, the time required for stent placement, which depends on the experience level of the bedside assistant. Unexpectedly, Chart D (CUSUM-COT) exhibited a curve similar in shape to Chart A (CUSUM-TOT), with an identical distribution of patients across the three phases. Furthermore, neither Trocar Placement and Docking Time nor Dedocking and Skin Closure Time showed a statistically significant difference among the three phases ($p > 0.05$). This may be explained by the fact that these steps were performed by surgical residents at varying levels of training, who rotated throughout the study period.

The most compelling result is shown in Figure 3. Here, we conducted a CUSUM analysis using a composite parameter influenced by TOT, success of the procedure and complications. This composite model altered the LC, increasing the number of cases required to exit the introductory phase from 4 to 17, a statistically significant difference. These findings underscore the importance of incorporating multiple performance metrics—not just time—into LC analyses. Unlike Kassite et al. [10], who included all types and grades of complications, we opted to include only major urological complications. We believe that minor or unrelated complications may not be specific to RALP and could confound the analysis.

In summary, our findings suggest that although the surgeon transitioned out of the introductory phase after 4 cases when assessed by TOT alone, a more comprehensive evaluation incorporating SF and CF revealed that 17 cases were required.

These preliminary results suggest that, although the CUSUM analysis of operative time indicates the surgeon has reached the mastery phase, the CUSUM curve for the composite parameter still places the surgeon in the proficiency phase, indicating that further experience is required to achieve full mastery.

We believe that future LC assessments in RALP should always include multiple parameters to provide a more accurate and clinically meaningful representation of surgical proficiency.

Limitations of the study

The main limitation of this study is the small number of cases. In addition, the composite parameter we used is not validated in the literature, and the weighting of complications is somewhat arbitrary. Furthermore, the minimum follow-up period is relatively short.

Conclusions

This prospective study highlights how LC analysis in RALP varies depending on both the parameter evaluated and the reference value used in CUSUM analysis.

In our experience, while the surgeon achieved the mastery phase after only 10 cases when assessed based on operative time alone, the CUSUM curve incorporating a composite parameter—including operative time, surgical success, and major urological complications—indicated that the surgeon remained within the proficiency phase even at the 22nd case. These findings suggest that relying solely on time-based metrics may underestimate the complexity and duration of the actual learning process.

We propose that future LC assessments in RALP should be guided by standardized study protocols, developed through consensus among pediatric urologists, to define the most appropriate and multidimensional parameters. This would allow for a more comprehensive and accurate characterization of the LC in RS for UPJO.

Conflict of interest

None.

Figures and tables

Table1 Demographic, operative, and postoperative data. Values are presented as mean ± standard deviation (range: minimum–maximum) or as number (%).

	Patients (n=22)	
Preoperative		
Age at diagnosis (years)	1.7 ± 3.7 (0-12)	
Age at surgery (years)	3.8 ± 4.0 (0.4-12.6)	
Prenatal diagnosis	16 (72.2%)	
Gender		
Male	14 (63.6%)	
Female	8 (36.4%)	
Weight	17.1 ± 11.8 (6-43)	
Laterality (right/left)	7 (31.8%) / 15 (68.2%)	
Crossing vessel	9 (59.1%)	
Pain	5 (22.7%)	
UTI	5 (22.7%)	
Arterial hypertension	1 (4.5 %)	
CKD	0	
Intraoperative		
Console operative time (minutes)	109.2 ± 21.1 (80-155)	
Total operative time (minutes)	158.1 ± 22.5 (119-210)	
Trocar Placement and Docking Time (minutes)	24.6 ± 8.2 (10-45)	
Dedocking and Skin Closure Time(minutes)	24.2 ± 9.3 (9-48)	
Ureteral stent	22 (100%)	
Drain	6 (27.3 %)	
Conversion	0	
Intraoperative complications ≥ 3b	1 (4.5%)	
Postoperative		
Length of hospitalisation (days)	3.8 ± 3.9 (0-19)	
Catheter (days)	2.3 ± 3.6 (0-17)	
Drain (days)	1.5 ± 3.4 (0-14)	
Stent (days)	51.1 ± 37.5 (2-161)	
Postoperative complications ≥ 3b		
Overall	5 (22.7 %)	
Urological	4 (18.2 %)	
Re-stentig for leak/stenosis	2 (9.1%)	
RALP failure (Redo RALP)	2 (9.1%)	
Length of follow-up (months)	11.6 ± 8.7 (1.7-29.9)	
Imaging data before and after surgery		
Preoperative US	22 (100%)	
Preoperative fMRU	18 (81%)	
Preoperative MAG3 renal scan	11 (50%)	
Postoperative US	22 (100%)	
Postoperative fMRU	5 (22.7%)	
Postoperative MAG3 renal scan	0 (0%)	
Postoperative US APD < Postoperative US APD at last follow-up	22 (100%)	
	Post-operative	Post-operative
US APD (mm)	27.7 ± 12.8 (15-79)	8.7 ± 6.9 (0-30)
fMRU APD (mm)	30.6 ± 15.0 (15-83)	22 ± 13.2 (12-45)
Split function of the affected kidney at fMRU (%)	33.4 ± 9.6 (18-51)	40.0 ± 7.8 (28-48)

Figure 1 Cumulative sum (CUSUM) chart for total operative time (TOT).
A. Based on the mean TOT of the operating surgeon (109.2 minutes).
B. Based on the mean TOT for RALP reported by Ekin et al (150 minutes).
C. Based on the mean TOT for RALP reported by Silay et al. (173.1 minutes).

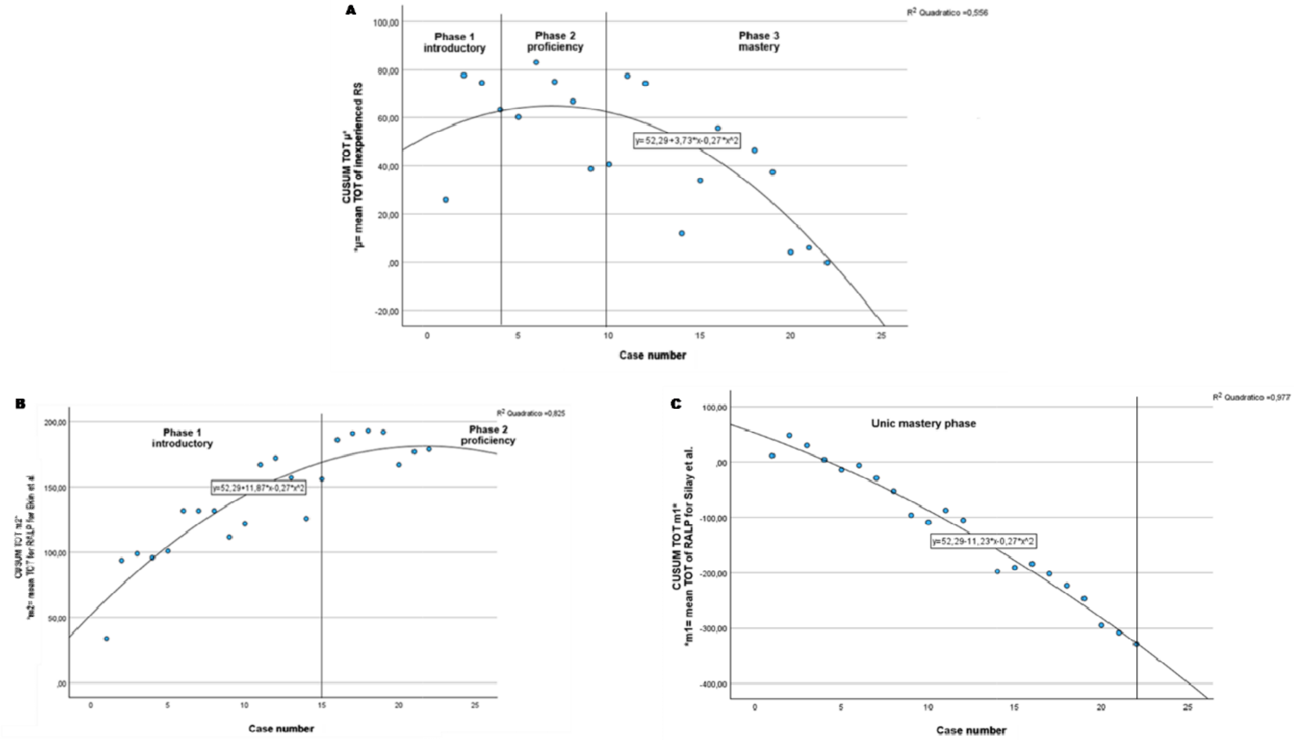


Figure 2 Comparison between cumulative sum (CUSUM) charts for total operative time (TOT) and console operative time (COT).
A. CUSUM chart based on the mean TOT of the operating surgeon.
D. CUSUM chart based on the mean COT of the operating surgeon.

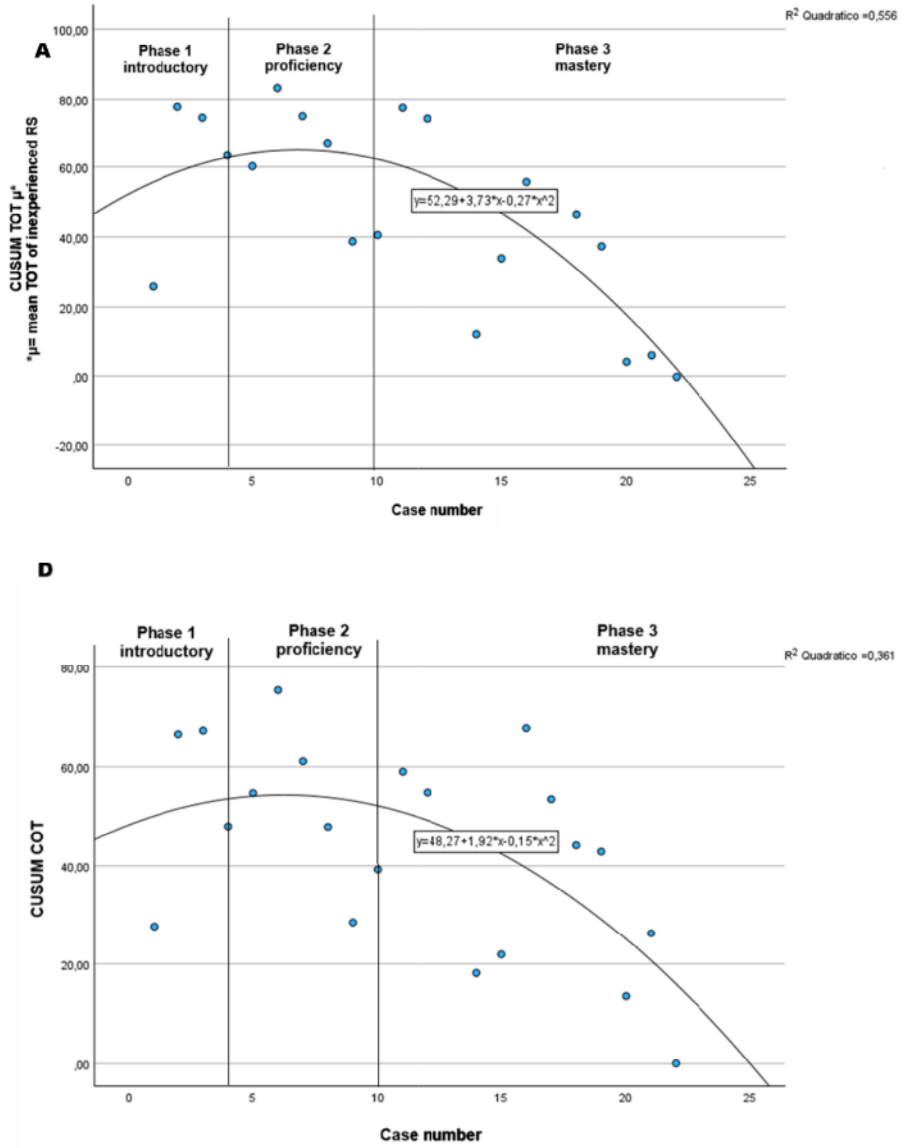
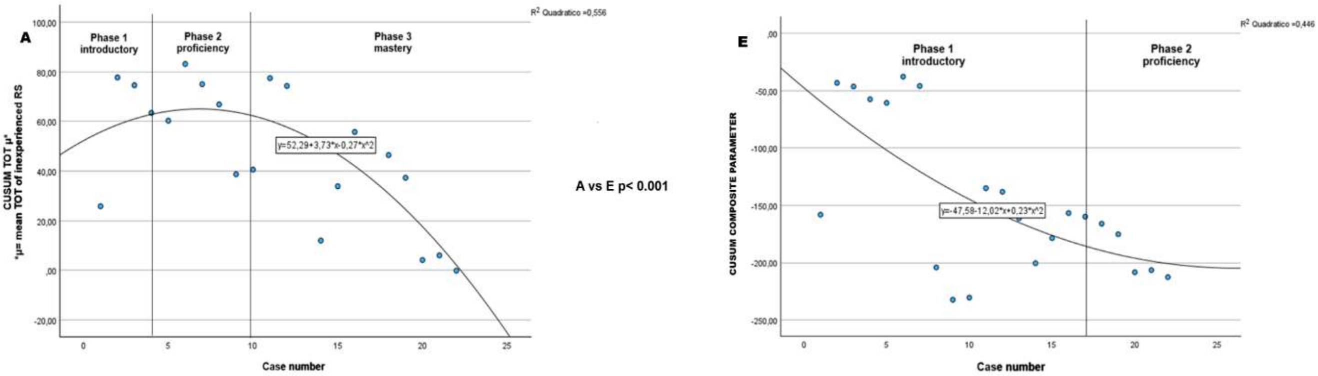


Figure 3 *Comparison between cumulative sum (CUSUM) charts for total operative time (TOT) and a composite parameter.*
A. CUSUM chart based on the mean TOT of the operating surgeon.
E. CUSUM chart based on the mean composite parameter (mean TOT of the operating surgeon × success factor 1 × complication factor 1).
The phases identified in chart A were statistically significantly different from those in chart E (p < 0.001).



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