Enhancing outcomes and accelerating learning curves in open pyeloplasty: Role of surgical mentorship

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ABSTRACT

Introduction: We aimed to evaluate the impact of surgical mentorship on case outcomes and learning curves of early-career surgeons performing pediatric open pyeloplasty.
Methods: Using an institutionally maintained prospective case log, we retrospectively analyzed all open pyeloplasty cases consecutively performed by an index junior academic surgeon under the mentorship of a senior surgeon between April 2020 and May 2023. The mentor was available for all cases and scrubbed in for early cases, with decreasing direct involvement over time. The data collected included case characteristics, operative times, followup durations, and surgical complications within a two-year postoperative period. A cumulative sum (CUSUM) analysis was employed to identify peaks, plateaus, and trends for complications (defined as Clavien-Dindo classification ≥3b) and operative time.
Results: We analyzed 54 open pyeloplasty cases performed under surgical mentorship and categorized them into four phases using CUSUM analysis. Based on this, the junior surgeon reached the competency-proficiency phase between the 12th and 26th case, demonstrating

KEY MESSAGES

- Cumulative sum (CUSUM) analysis identified four distinct learning phases in surgical training.
- Complication rates declined as operative experience and mentorship progressed.
- Mentorship enabled the attainment of proficiency and safe handling of complex cases in the case-mix phase.

consistent technical skill development, reduced operative times, and satisfactory outcomes under mentorship. In the case-mix phase (45^{th}–54^{th} case), a slight increase in operative time was noted, coinciding with more complex cases and increased trainee involvement.
Conclusions: This analysis demonstrated that surgical mentorship for junior academic surgeons facilitates early technical proficiency in pediatric open pyeloplasty, enabling them to safely achieve comparable outcomes early in their careers. These findings suggest that mentorship is key to ensuring satisfactory surgical outcomes during the initial stages of a surgeon's learning curve.

INTRODUCTION

Ureteropelvic junction obstruction (UPJO) is one of the most common congenital anomalies of the kidney and urinary tract, accounting for up to two-thirds of hydronephrosis cases.[1] While minimally invasive pyeloplasty—particularly robotic-assisted techniques—has gained momentum in recent years, the open surgical approach remains a cornerstone, especially for infants, young children, and in resource-limited settings. With robotic platforms costing up to $2.5 million upfront, along with significant annual maintenance fees, many healthcare systems worldwide cannot justify or sustain this investment. In these environments, proficiency in open pyeloplasty is both advantageous and essential. Moreover, the procedure's success rates exceed 95%, irrespective of whether it is performed via open, laparoscopic, or robotic techniques.[2-4] Patients undergoing open pyeloplasty are, therefore, not at a clinical disadvantage despite the allure of advanced technology. As such, surgeons must develop and preserve the technical skills required for open pyeloplasty, particularly during the transition from training to independent practice, a formative period that shapes surgical competence and confidence.

In this challenging context, surgical mentorship is an indispensable element in shaping the careers of early-stage surgeons. This mentorship offers a structured pathway to mastering essential surgical skills, fostering confidence, advancing professional development, and ultimately enhancing patient outcomes.[5-8] This mentorship concept has been demonstrated in other areas of pediatric urology as well as in other specialties in shortening the learning curve, reducing complications, and enhancing surgical success rates.[7, 9] Herein, we aimed to explore the impact of formal surgical mentorship on the learning curves and surgical outcomes of junior surgeons performing pediatric open pyeloplasty, with the hypothesis that junior surgeons can produce learning curves similar to those of senior surgeons [10] resulting in displayed competence, reduced operative times, and lower complication rates.

METHODS

Following approval by the institutional research ethics board (IRB No. 1000061750), we used an institutionally maintained prospective case log from the EPIC electronic health record system to retrospectively access a comprehensive dataset spanning from January 2020 to May 2023. We focused on pediatric patients diagnosed with UPJO treated by an index junior surgeon in the first three years of training under the guidance of a senior mentor with more than 15 years of experience.

All consecutive open pyeloplasty cases performed by the index junior surgeon were included, and data on preoperative, intraoperative, and postoperative variables were collected. To ensure data integrity, another research team member performed a random 20% audit, and the dataset was further cross-referenced to a prospectively collected database on institutional pyeloplasty outcomes [10-12]. Data collected from electronic medical records included patient demographics (age and sex), surgical metrics (operative time, hospital stay), preoperative diagnostics, and associated anomalies. The primary outcomes, operative time, and surgical complications were categorized using the Clavien-Dindo classification system.[13]

The mentorship model was part of a structured departmental initiative to support new faculty during the transition to independent practice, emphasizing an adult-learner framework. The junior surgeon was paired with a senior pediatric urologist with over 15 years of experience. For the initial few cases, the mentor was scrubbed in and provided direct intraoperative guidance. Subsequent cases were performed independently, with the mentor available to provide real-time input only as needed, fostering autonomy in a supported environment. This approach prioritized trust and confidence in the junior surgeon's competence while ensuring patient safety. Post-operative discussions were held selectively for technically challenging cases, focusing on decision-making and refinement of technique. The mentorship extended to other complex pediatric urology procedures, but this study focused exclusively on open pyeloplasty.

We utilized the Cumulative Sum (CUSUM) methodology previously described by Chua et al. and Kim et al.[10, 14] to analyze the surgeon's progress through four distinct phases: learning, competency, proficiency, and case-mix.[10, 15] These phases illustrate the surgeon's initial experiences, consistent improvements, attainment of proficiency, and handling of complex cases. Learning curve plots were created using CUSUM analysis to track changes in operative time and surgical complications.[14, 15] CUSUM is a sequential monitoring technique that tracks the cumulative deviation of each case from the overall mean. Upward slopes on the CUSUM plot indicate cases with operative times or complication rates above the mean, while downward slopes indicate improved performance as outcomes fall below the mean. Changes in slope direction mark transitions between learning phases.

For the initial case, the CUSUM for operative time (CUSUM-OT) was determined by subtracting the overall mean operative time from that of the first patient. For every subsequent patient, the new CUSUM-OT value was calculated by adding the difference between the patient's operative time and the overall mean to the previous CUSUM-OT value. This sequential calculation was continued until the final patient's CUSUM-OT reached zero.

Similarly, the complication learning curve was assessed using the CUSUM method (CUSUM-CR) and plotted against the series of open pyeloplasty procedures performed. For this analysis, we set the type I and II error rates to 0.05 and 0.1, respectively. CUSUM parameters were defined based on the existing literature and institutional data, setting specific thresholds for acceptable and unacceptable complication rates to identify significant shifts in the learning curve. An acceptable failure rate was defined as 7% of the prior report on the senior surgeon's complication rate ($p_0 \approx 0.07$), while a rate of $p_1 \approx 0.16$—based on early reports of the upper range of reported complication rate and the threshold agreed upon by the research team.[10]

A combined graph of the CUSUM-OT and CUSUM-CR plots was used to visualize the overall learning curve across the open pyeloplasty series. Following the modifications suggested by Yap et al., Phase 1 was designated as the period from the beginning of the evaluation until the case at which the CUSUM-OT reached its peak and the CUSUM-CR dropped below a set threshold (with both parameters a and b set at 0.1).[15] Phase 2 comprised all cases following this peak until the end of the evaluation period. Finally, bivariate analyses were conducted to compare the outcomes and case characteristics before (Phase 1) and after (Phase 2) reaching the peak.

Categorical variables were summarized using descriptive statistics and presented as counts and percentages, whereas continuous variables were summarized as means and standard deviations. Fisher's exact test and one-way ANOVA were used to assess the differences in categorical and continuous variables across the four phases of the learning curve. Statistical analyses were performed using IBM® SPSS® version 27, with the significance set at a p-value of <0.05.

RESULTS

Study cohort

A total of 54 consecutive open pyeloplasty cases had a mean age at surgery of 15.49 ± 27.28 months, with the majority being male (79.6%) and most (61.1%) being left-sided. Stenting was employed in all cases, with Salle stents used in 75.9% of the surgeries and double-J stents in the remaining cases. Associated renal anomalies were noted in 37% of patients, including bilateral UPJO, intrinsic UPJO with crossing vessels, ectopic kidney, duplex kidney, stone, high insertion, and concomitant ureterovesical junction obstruction. The mean follow-up duration was 21.63 ± 14.14 months (Table 1).

Operative time and learning curve analysis

The average operative time across all cases was 141.26 ± 34.82 minutes. CUSUM analysis revealed distinct phases of the surgeon's learning curve. The learning phase (Phase 1) encompassed the first 11 cases and was characterized by variability in operative times and a peak in the CUSUM curve. During the competency phase (Phase 2), observed between the 12th and 26th cases, operative times began to stabilize with an apparent reduction in variability and improved efficiency. By the proficiency phase (Phase 3), spanning cases 27 to 44, the operative times consistently decreased, reflecting the surgeon's growing technical expertise. The case-mix phase (Phase 4), from the 45th to the 54th cases, involved more complex surgeries, including those with increased trainee involvement. A statistically and clinically significant increase in operative time was observed during this phase, likely reflecting the greater complexity of cases and increased educational involvement. Notably, the study period did not extend far enough to capture a definitive "mastery" phase (Phase 5), limiting our ability to assess long-term plateau in operative efficiency.

Complications and outcomes

The overall complication rate for the study cohort was 5.5%, with complications classified as Clavien-Dindo ≥ 3b requiring redo pyeloplasty or stent dilation. Operative times and complications were analyzed across the learning curve, with the most efficient times recorded during the Proficiency Phase. Complication rates were the highest during the learning phase, with one redo pyeloplasty recorded. Complications decreased during the competency and proficiency phases, reflecting the surgeon's improved technical skills and decision-making abilities. No complications requiring major reinterventions were reported during the case-mix phase, despite the increased complexity of cases, as shown by the higher proportion of renal anomalies, concomitant procedures, and relatively older patients during this phase. Although complication rates were not statistically significant across phases due to the low overall frequency, the rates did show a declining trend. Factors such as patient laterality, associated renal anomalies, and stent type did not differ significantly across phases, indicating consistency in case characteristics throughout the study period.

DISCUSSION

The findings of this study underscore the potential value of formal surgical mentorship in the learning curve of junior surgeons performing open pyeloplasty. The accelerated progression through the learning phases, as evidenced by reduced operative times and low complication rates, highlights the impact that mentorship may have on enhancing surgical proficiency. Although causal inferences cannot be made due to the observational design, the use of CUSUM analysis enabled detailed, phase-specific tracking of performance over time within a real-world mentorship context.

CUSUM analysis delineated distinct phases in the surgeon's learning curve: learning, competency, proficiency, and case-mix. The observed complication trends aligned with the learning curve phases identified through the CUSUM analysis (Figure 1). The transition from the Competency to Proficiency Phase in our study occurred between the 12th and 27th case. The progression through these phases appears to be notably rapid compared with the traditional learning curves reported in the literature. For instance, a study by Kim et al.[10] utilizing CUSUM analysis reported this transition between the 13th and 70th case for an index surgeon performing open pyeloplasty. Furthermore, the proportion of complications during the early (learning and competency) phases in our series appeared lower compared to that reported by Kim et al.[10], although statistical comparison between the two studies could not be performed. While this difference may reflect the positive influence of mentorship, discrepancies may also arise from differences in the number of cases analyzed and the overall study design. Changes in practice patterns and era-related factors between the index surgeon in the Kim et al. [10] study and the junior surgeon in our study further complicate direct comparisons. Additionally, the mastery phase described by Kim et al.[10] could not be assessed in our study because of the limited number of cases, restricting our ability to evaluate the full trajectory of skill acquisition. Nevertheless, the earlier attainment of proficiency observed in our study suggests that formal mentorship played a crucial role in expediting technical development.

While technical improvement is expected with increasing case volume, our findings suggest that structured mentorship may play an additive role in accelerating the junior surgeon's progression. The mentor's role evolved across the learning curve: in the early learning phase, the mentor was scrubbed in and directly involved in most steps of the operation. Upon reaching the competency phase, the mentor largely adopted a supervisory or observational role, providing support only when needed. This progressive reduction in hands-on involvement coincided with improvements in operative time and complication rates, suggesting a mentorship-facilitated path to independence. While we compared our learning curve to the Kim et al. [10] study, this external comparison is not equivalent to a direct control group. As such, we acknowledge that it remains challenging to fully isolate the effect of mentorship from improvement due to case volume alone. Future studies using matched controls or randomized designs may help delineate these contributions more clearly. Although the role of mentorship in pediatric surgical procedures, such as open pyeloplasty, has not been widely explored, its impact in other surgical disciplines has been well established. Igai et al. found that mentorship reduced the attainment of proficiency from 40 cases to 30 cases in uniportal thoracoscopic lobectomy.[16] Maeda et al. found that expert supervision enabled junior surgeons to acquire technical skills for both open and laparoscopic colorectal surgery simultaneously, with comparable learning curves.[17] Furthermore, Jenkins et al. found that a two-mentor training program accelerated proficiency gain compared to a single-mentor program in laparoscopic colorectal resections, suggesting a role for various mentorship programs.[18]

Additionally, mentorship ensured that the outcomes during the learning phase remained within acceptable ranges, preventing significant adverse events often associated with the early stages of independent practice. The overall complication rate in this study was 5.5%, with complications classified as Clavien-Dindo ≥ 3b. This is consistent with the existing literature, which reports complication rates for open pyeloplasty ranging from 3% to 10%.[10] The low complication rate observed, even during the early phases of the learning curve, underscores the protective effect of mentorship in mitigating potential adverse outcomes. Although studies in other surgical disciplines did not show that mentorship significantly reduced complication rates, it still suggests that mentorship can be safely employed without compromising patient safety.[9, 19] Operative time is a critical indicator of surgical efficiency and proficiency. The mean operative time in this study was 141.26 minutes, with a decrease observed as the surgeon progressed through the learning phases. This aligns with findings from other studies, including Kim et al.[10] who reported an operative time of 130 minutes with a decreasing trend as surgeons gained experience. The reduction in operative time reflects the positive impact of mentorship on enhancing surgical efficiency, which further aligns with reports in other surgical areas.[9, 17] The case-mix phase, characterized by the introduction of more complex cases and increased trainee involvement, did not result in a significant increase in complication rates. This suggests that the foundational skills developed through mentorship enabled junior surgeons to handle increased case complexity without compromising patient safety. Beyond technical skill acquisition, mentorship fosters the development of decision-making abilities, professional behaviour, and confidence, all of which contribute to improved patient outcomes.[20, 21] The benefits gained from mentorship are also mutual, with mentors gaining satisfaction, professional development, advancements in teaching skills, and an opportunity to participate in shared learning.[5, 22-24] These benefits may inform future curriculum and training model design, particularly in pediatric surgery, where specialized procedures, such as open pyeloplasty, require refined technical skills.

Given the ongoing need to maintain expertise in open pyeloplasty, particularly in resource-limited settings, where access to advanced urological techniques and technology may be limited, mentorship can play a crucial role in strengthening surgical training worldwide. Awuah et al.[25] in a review of the existing literature, reported that surgical mentorship programs in low- and middle-income countries enhance local surgical capacity, support skill development, improve patient outcomes, and contribute to more effective use of available resources and technology. In such contexts, there may also be opportunities to leverage telementoring to help bridge educational gaps and ensure competency in essential procedures such as open pyeloplasty.[26, 27]

This study had several limitations that should be considered. First, the analysis was conducted with a single junior surgeon under mentorship at one institution, which may limit the generalizability of the findings to broader populations and other surgical settings. Additionally, the retrospective methodology introduces the inherent limitations of this study design. We also note that only major complications (Clavien-Dindo ≥3b) were analyzed, and minor complications—though clinically relevant—were not systematically collected due to the retrospective design. The small sample size may further limit statistical power and generalizability, given the low overall complication rate for open pyeloplasty. Additionally, qualitative aspects of surgical performance, such as intraoperative decision-making confidence or adaptability, were not assessed but are important considerations in future studies. Furthermore, the lack of a control group limits our ability to separate the effects of mentorship from the natural improvements that occur with increasing case volume and experience. Despite these limitations, this study has several strengths. It provides a comprehensive analysis of the impact of mentorship on the learning curve for open pyeloplasty, a complex procedure that is often underrepresented in learning curve studies. CUSUM analysis enabled the objective quantification of key milestones, such as transitions to competency and proficiency, which are critical for evaluating surgical skill acquisition. Moreover, this study highlights the importance of mentorship in mitigating early complications and enhancing technical efficiency, providing practical insights for surgical training programs.

Future studies should explore multi-institutional and multi-surgeon cohorts to validate the generalizability of these findings. Incorporating qualitative assessments, such as surgeon confidence and decision-making skills, alongside objective metrics, such as operative time and complication rates, would provide a more holistic evaluation of the mentorship's impact. Additionally, future work should explore the reciprocal benefits for mentors, including professional development, teaching satisfaction, and skill reinforcement, which may further support the integration of formal mentorship into surgical training programs.

CONCLUSION

This study demonstrates the significant role formal surgical mentorship may have in accelerating the learning curve and improving the outcomes of junior surgeons performing open pyeloplasty. Mentorship facilitated the early attainment of surgical competency and proficiency, minimized complications during the critical early phases, and successfully managed complex cases in the later phases. These findings advocate for the widespread implementation of formal mentorship programs in surgical education to optimize training, enhance patient safety, and ensure the development of proficient and confident surgeons. By addressing gaps in traditional training approaches, mentorship has the potential to modernize the landscape of surgical education and practice.

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FIGURES AND TABLES

Figure 1. Phases in the cumulative sum (CUSUM) analysis reflect slope changes in the cumulative curve. The orange line shows operative-time trends, and the blue line highlights outcome (complication) deviations. Upward slopes indicate values above the mean, downward slopes indicate values below the mean, and slope changes mark phase transitions—from learning to improvement (Phase 1), stability to competency (Phase 2), decline in failure rate and greater efficiency indicating proficiency (Phase 3), and adjustment with case-mix (Phase 4).

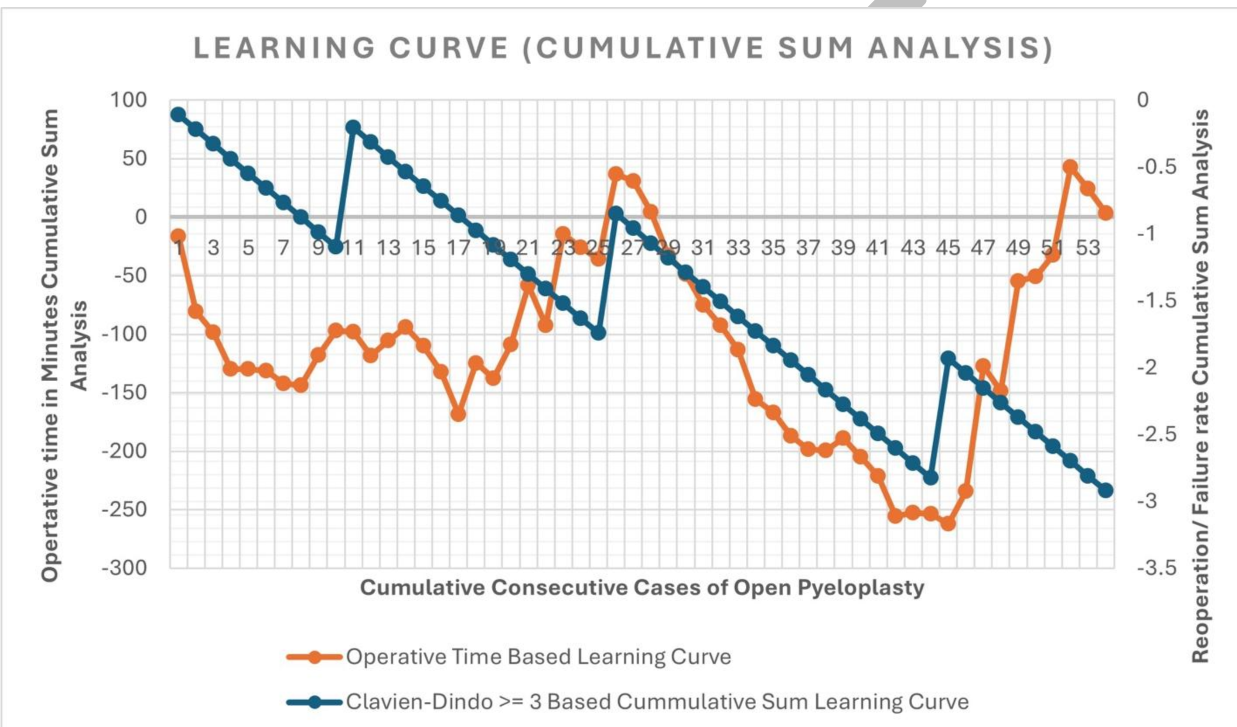

Table 1. Case characteristics, operative time, followup duration, and complication rates

Categorical, n (%)	**Overall (n=54)**	**Phase 1 (n=11)**	**Phase 2 (n= 15)**	**Phase 3 (n= 19)**	**Phase 4 (n= 9)**	**Fisher's exact test p**
Sex (male)	43 (79.6%)	9 (81.8%)	9 (60%)	16 (84.2%)	9 (100%)	0.121
Laterality (left)	33 (61.1%)	5 (45.5%)	10 (66.7%)	11 (57.9%)	7 (77.8%)	0.504
Concomitant procedures	14 (25.9%)	2 (18.2%)	7 (46.7%)	2 (10.5%)	3 (33.3%)	0.094
Associated renal anomaly	20 (37.0%)	4 (36.4%)	8 (53.3%)	4 (21.1%)	4 (44.4%)	0.267
Stent used (salle)	41 (75.9%)	11 (100%)	9 (60%)	14 (73.7%)	7 (77.8%)	0.105
Stent used (double J)	13 (24.1%)	0 (0%)	6(40%)	5 (26.3%)	2 (22.2%)	
Redo-pyeloplasty or dilatations	3 (5.5%)	1 (9%)	1 (6.7%)	1 (5.3%)	0 (0%)	0.771
Redo pyeloplasty only	2 (3.7%)	1 (9.1%)	1 (6.7%)	0 (0%)	0 (0%)	0.416
Continuous, mean (SD)						**One-way ANOVA**
Age at surgery (months)	15.49 (27.28)	19.51 (39.68)	18.55 (21.29)	6.61 (3.40)	24.26 (42.77)	0.345
OR time (min)	141.26 (34.82)	132.27 (24.58)	150.2 (37.62)	125.47 (13.81)	170.67 (50.44)	0.005
Followup (months)	21.63 (14.14)	14.26 (17.88)	27.22 (15.16)	23.20 (12.54)	18.02 (6.37)	0.106
Hospital stay (hrs)	24.41 (17.02)	39.03 (21.74)	43.07 (25.39	29.35 (8.03)	33.38 (7.64)	0.142

OR: operating room; SD: standard deviation.