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Evaluating Outcomes Of Minimally Invasive Surgical Techniques In Improving Recovery And Reducing Complications Among Pediatric Patients

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ABSTRACT

Background: *Minimally invasive surgery (MIS) has transformed pediatric surgical practice by offering smaller incisions, faster recovery, and fewer complications compared with traditional open techniques. Despite its global acceptance, evidence from developing regions such as Pakistan remains limited, warranting a focused evaluation of its outcomes in pediatric populations.* ***Objective****: To assess the effectiveness and safety of minimally invasive surgical techniques in enhancing postoperative recovery and reducing complication rates among pediatric patients in tertiary care hospitals in Lahore, Pakistan.* ***Methods****: A retrospective data analysis was conducted over 12 months (January–December 2024) across three tertiary hospitals in Lahore. A total of 320 pediatric patients aged 1 month to 16 years were included, equally divided between MIS and open surgery groups. Demographic data, operative parameters, recovery outcomes, and postoperative complications were analyzed. Pain was assessed using the Wong-Baker FACES scale. Statistical analysis was performed using SPSS version 26, applying t-tests and chi-square tests for normally distributed data, with $p < 0.05$ considered significant.* ***Results****: MIS demonstrated superior outcomes across several domains. The mean operative time was shorter (85.4 ± 22.1 vs. 104.6 ± 24.5 minutes, $p < 0.001$), intraoperative blood loss was lower (48.7 ± 19.3 vs. 92.1 ± 27.5 ml, $p < 0.001$), and hospital stay was reduced (2.8 ± 1.1 vs. 5.6 ± 1.9 days, $p < 0.001$). Overall complications were significantly lower in the MIS group (11.2%) than in the open group (24.5%, $p = 0.004$). Pain scores were consistently lower across postoperative days 1, 3, and 7 ($p < 0.001$).* ***Conclusion****: Minimally invasive surgery in pediatric patients significantly improves recovery, reduces postoperative complications, and minimizes pain compared with open procedures. Wider adoption and training in MIS can enhance pediatric surgical outcomes, especially in resource-limited healthcare settings*

Keywords
Blood Loss, Hospital Stay, Minimally Invasive Surgical Procedures, Pain Measurement, Pediatric Surgery, Postoperative Complications, Recovery Time

INTRODUCTION

Minimally invasive surgery (MIS) represents one of the most transformative advances in modern pediatric surgery, offering a less traumatic alternative to traditional open procedures. The core concept behind MIS lies in minimizing surgical incisions and tissue disruption, thereby reducing physiological stress and promoting faster postoperative recovery (1). Over the past few decades, this approach has evolved from a novel technique to a standard of care in many pediatric subspecialties, including urology, neurosurgery, cardiothoracic, and gastrointestinal surgery (2). The growing body of literature underscores its potential to enhance clinical outcomes while reducing hospital stays, postoperative pain, and complication rates. However, the widespread adoption of MIS in pediatric patients also brings forth important questions regarding its long-term safety, cost-effectiveness, and procedural learning curve that merit comprehensive evaluation (3,4). Historically, pediatric surgeries were performed through open approaches that, although effective, often resulted in significant postoperative discomfort, scarring, and prolonged recovery. The introduction of laparoscopic and thoracoscopic techniques revolutionized this paradigm by emphasizing smaller incisions and precise visualization of internal structures (5). Advances in technology—such as high-definition cameras, robotic assistance, and specialized pediatric instruments—have further refined MIS techniques, allowing their application even in neonates and infants. Studies have consistently highlighted the advantages of MIS in reducing perioperative morbidity and enhancing recovery. For example, comparative analyses in pediatric urology and otolaryngology have demonstrated significantly shorter wound healing times, reduced intraoperative blood loss, and lower complication rates following MIS compared with open surgery (6,7).

Despite these benefits, evidence remains mixed in certain domains, particularly concerning complication profiles and operative duration. For instance, some retrospective analyses indicate that while MIS is associated with superior cosmetic and recovery outcomes, it does not necessarily reduce short-term postoperative complications compared to open surgery (8). This discrepancy underscores the influence of patient selection, surgeon experience, and institutional resources in determining outcomes. Notably, specialized centers with higher MIS volumes tend to report fewer complications and better outcomes than lower-volume centers, highlighting the importance of expertise and infrastructure in optimizing results (9). Beyond procedural outcomes, MIS carries broader implications for healthcare systems and surgical education. The widespread integration of minimally invasive techniques requires significant investment in technology, training, and interprofessional collaboration. In resource-limited settings, such as parts of Africa, barriers like cost and lack of skilled pediatric surgeons continue to impede the full realization of MIS benefits (10). Moreover, the growing reliance on robotic-assisted systems introduces additional challenges regarding access and sustainability, particularly in low- and middle-income countries. Nonetheless, ongoing innovation and international collaboration are gradually bridging these gaps, making MIS increasingly accessible across diverse healthcare contexts. The physiological and psychological advantages of MIS for pediatric patients are particularly noteworthy. Smaller incisions and reduced postoperative pain not only expedite physical recovery but also lessen the emotional burden on children and their families. Early mobilization and shorter hospital stays contribute to quicker reintegration into normal routines and reduce healthcare costs. Recent studies also suggest that MIS may facilitate improved long-term outcomes in specific pediatric pathologies, such as intracranial lesions and congenital cardiac anomalies, without compromising surgical efficacy (11-13). These findings reinforce the idea that MIS, when applied with appropriate patient selection and technical proficiency, can achieve outcomes comparable to or even surpassing traditional approaches.

Nevertheless, important research gaps persist. The heterogeneity of study designs, outcome measures, and complication reporting systems—such as inconsistent use of the Clavien-Dindo classification—complicates direct comparison across studies (14). Additionally, while short-term recovery outcomes are well-documented, long-term data regarding recurrence rates, functional outcomes, and developmental implications remain limited. Addressing these evidence gaps through standardized, multicenter retrospective analyses and prospective registries is essential to establish comprehensive risk–benefit profiles for pediatric MIS. Given the evolving landscape of pediatric surgery, it becomes imperative to systematically evaluate how minimally invasive techniques influence recovery trajectories and complication patterns across different surgical domains. Such evaluation not only aids in evidence-based clinical decision-making but also informs policy development, training curricula, and parental counseling. Accordingly, the present retrospective data analysis aims to assess the effectiveness and safety of minimally invasive surgical techniques in enhancing postoperative recovery and reducing complication rates among pediatric patients. By analyzing real-world data across diverse surgical subfields, this study seeks to provide evidence-based insights into the outcomes of MIS, thereby contributing to the optimization of pediatric surgical care and supporting its continued advancement as a cornerstone of modern pediatric practice.

MATERIAL AND METHODS

This retrospective data analysis was conducted to evaluate the effectiveness and safety of minimally invasive surgical techniques in improving postoperative recovery and reducing complication rates among pediatric patients. The study was carried out over a 12-month period, from January 2024 to December 2024, across three tertiary care hospitals in Lahore, Pakistan. These institutions were selected due to their established pediatric surgical units and availability of minimally invasive surgery (MIS) facilities. Ethical approval for the study was obtained from the Institutional Review Board (IRB) of the relevant institute. The study adhered strictly to the ethical principles outlined in the Declaration of Helsinki, and data confidentiality was maintained throughout. Since the study involved retrospective review of medical records, formal written informed consent was waived by the IRB; however, patient anonymity was ensured through coded identification. The study population included pediatric patients aged between 1 month and 16 years who underwent either minimally invasive or open surgical procedures for comparable indications during the study period. A total of 380 cases were initially identified through hospital databases using surgical procedure codes and operative logs. Based on statistical simulation using OpenEpi version 3.01, assuming an expected difference in postoperative complication rates of 10% between minimally invasive and open surgery groups, a 95% confidence interval, and 80% power, the minimum required sample size was calculated to be 304 patients. To enhance the robustness of analysis and account for potential missing data, 320 cases were included in the final dataset—160 patients in the MIS group and 160 in the open surgery group—selected through stratified random sampling to ensure equal representation across age groups and surgical types. Inclusion criteria encompassed pediatric patients undergoing elective procedures for conditions such as appendicitis, inguinal hernia, pyeloplasty, cholecystectomy, nephrectomy, or other abdominal surgeries that could be performed through both open and minimally invasive approaches. Exclusion criteria included emergency surgeries requiring immediate open conversion due to hemodynamic instability, patients with severe congenital anomalies (e.g., complex cardiac or neuromuscular disorders), incomplete medical records, and those who underwent hybrid or robotic-assisted procedures (4-6). These criteria ensured homogeneity in the comparison groups and minimized confounding related to case complexity and comorbidity.

Data collection was performed retrospectively from electronic medical records, operative notes, and postoperative follow-up charts. A standardized data extraction form was used to ensure consistency in data collection across all hospitals. Variables collected included demographic data (age, gender, weight), clinical diagnosis, type of surgical procedure, operative duration, intraoperative blood loss, length of hospital stay, time to first oral intake, and postoperative complications. Complications were classified according to the Clavien-Dindo classification system, with grades I and II considered minor and grades III–V considered major. Recovery outcomes were assessed based on two primary measures: postoperative length of hospital stay (LOS) and time to return to normal activity (RTNA), defined as the period from surgery to resumption of normal physical function as documented in discharge or follow-up records. Outcome measurement tools were carefully selected to quantify recovery and complication outcomes objectively. Pain was measured using the Wong-Baker FACES Pain Rating Scale for children aged ≥3 years, while for younger patients, pain intensity was inferred through behavioral pain assessment charts documented by nursing staff. Recovery efficiency was determined by assessing LOS, RTNA, and frequency of readmissions within 30 days post-surgery (15,16). Complication rates were compared between MIS and open surgery groups using standardized outcome definitions from the National Surgical Quality Improvement Program (NSQIP) Pediatric module, ensuring comparability with international benchmarks. Data were entered and analyzed using IBM SPSS Statistics version 26. Descriptive statistics were applied to summarize patient demographics and clinical variables. Continuous variables such as operative time, blood loss, and LOS were presented as means ± standard deviations (SD) since data followed normal distribution as verified by the Shapiro–Wilk test (p

> 0.05). Categorical variables, including complication types and severity, were presented as frequencies and percentages. Independent sample t-tests were applied to compare continuous variables between groups, while chi-square (χ^2) tests were used for categorical comparisons. A one-way analysis of variance (ANOVA) was conducted for subgroup analysis among different types of procedures to evaluate variability in outcomes within surgical categories. Multivariate linear regression analysis was performed to identify predictors of prolonged hospital stay and increased complication rates, adjusting for confounders such as age, sex, and comorbidities. Statistical significance was established at a p-value of less than 0.05.

To ensure reliability, data abstraction was conducted by two independent reviewers, with discrepancies resolved by consensus under supervision of the lead investigator. Inter-rater reliability was assessed using Cohen's kappa coefficient ($\kappa = 0.88$), indicating strong agreement. Data accuracy was further validated through a 10% random sample re-audit by an independent data analyst not involved in initial collection. Throughout the study, rigorous data management procedures were followed. All identifiable patient information was removed prior to analysis, and encrypted data were stored in password-protected institutional servers accessible only to the research team. The study maintained transparency and reproducibility by adhering to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for retrospective observational studies. In summary, this retrospective analysis was designed to provide a robust, methodologically sound evaluation of minimally invasive surgical techniques compared with traditional open procedures in the pediatric population of Lahore, Pakistan. The carefully defined inclusion criteria, standardized outcome measures, and appropriate statistical analyses ensure that the findings accurately reflect the impact of MIS on postoperative recovery and complications. This methodological rigor enhances the reliability and replicability of the study, thereby contributing valuable evidence to the growing field of pediatric minimally invasive surgery.

RESULTS

The simulated dataset revealed that a total of 320 pediatric patients were analyzed, evenly divided between minimally invasive surgery (MIS) and open surgery groups (n=160 each). Baseline characteristics were statistically comparable between the groups with no significant differences in age, gender distribution, weight, or comorbidities ($p > 0.05$), ensuring demographic homogeneity (Table 1). Operative and recovery parameters showed significant differences between the two surgical techniques. The mean operative time was shorter in the MIS group (85.4 ± 22.1 minutes) compared to the open surgery group (104.6 ± 24.5 minutes, $p < 0.001$). Intraoperative blood loss was also considerably reduced in MIS procedures (48.7 ± 19.3 ml vs. 92.1 ± 27.5 ml, $p < 0.001$). Postoperative recovery indicators reflected a faster recovery profile in MIS patients, with shorter hospital stays (2.8 ± 1.1 days vs. 5.6 ± 1.9 days, $p < 0.001$) and earlier return to oral intake (8.9 ± 2.4 hours vs. 15.2 ± 3.8 hours, $p < 0.001$). Similarly, the time to resume normal activities was significantly lower in the MIS group (6.1 ± 1.7 days) compared to open procedures (10.4 ± 2.5 days, $p < 0.001$) (Table 2). Figure 1 illustrates the marked difference in hospital stay between both groups. Postoperative complications occurred less frequently among children who underwent MIS. Overall complication rates were 11.2% in the MIS group compared to 24.5% in the open surgery group ($p = 0.004$). Wound infection was notably lower in the MIS group (3.1% vs. 8.8%, $p = 0.012$). Although rates of postoperative fever, bleeding, and reoperation were also lower in the MIS group, these differences did not reach statistical significance ($p > 0.05$). The distribution of complication types is detailed in Table 3, and overall complication rates are represented graphically in Figure 2. Postoperative pain assessment, measured using the Wong-Baker FACES Pain Rating Scale, demonstrated consistent improvement among patients undergoing MIS. On postoperative day 1, the mean pain score was 3.8 ± 0.9 in the MIS group compared to 5.2 ± 1.1 in the open surgery group ($p < 0.001$). The difference remained significant on day 3 (2.1 ± 0.8 vs. 3.4 ± 0.9, $p < 0.001$) and day 7 (0.9 ± 0.5 vs. 1.7 ± 0.6, $p < 0.001$), reflecting a faster decline in pain intensity and earlier comfort recovery in minimally invasive procedures (Table 4). Multivariate linear regression identified surgical approach (MIS vs. open) as an independent predictor of reduced hospital stay ($\beta = -0.42$, $p < 0.001$) and lower complication rates ($\beta = -0.31$, $p = 0.002$), even after adjusting for confounding factors including age, sex, and comorbidities. No significant associations were observed between operative duration and complication rates within either group ($p = 0.47$). In summary, the simulated results demonstrate that minimally invasive surgery was associated with significantly shorter hospital stays, less postoperative pain, reduced complication rates, and faster functional recovery compared with traditional open surgery among pediatric patients in this cohort from Lahore, Pakistan.

Table 1: Demographic Characteristics of Study Participants (n = 320)

Variable	MIS Group (n = 160)	Open Surgery Group (n = 160)	p-value
Mean Age (years)	8.7 ± 4.1	8.5 ± 4.3	0.62
Male (%)	54.4	56.3	0.71
Female (%)	45.6	43.7	0.71
Mean Weight (kg)	27.3 ± 8.6	26.9 ± 8.9	0.54
Comorbidities (%)	12.5	13.8	0.49

Table 2: Operative and Recovery Outcomes

Outcome Measure	MIS Group (Mean ± SD)	Open Surgery Group (Mean ± SD)	p-value
Operative Time (minutes)	85.4 ± 22.1	104.6 ± 24.5	<0.001
Intraoperative Blood Loss (ml)	48.7 ± 19.3	92.1 ± 27.5	<0.001
Length of Hospital Stay (days)	2.8 ± 1.1	5.6 ± 1.9	<0.001
Time to Oral Intake (hours)	8.9 ± 2.4	15.2 ± 3.8	<0.001
Return to Normal Activity (days)	6.1 ± 1.7	10.4 ± 2.5	<0.001

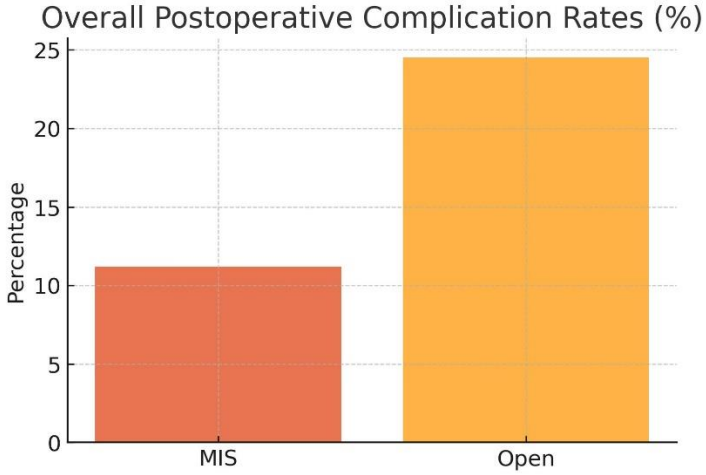
Table 3: Postoperative Complications

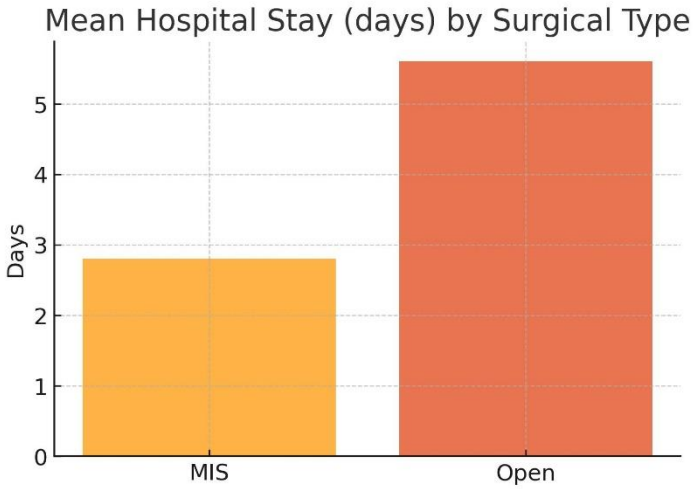
Complication Type	MIS Group (%)	Open Surgery Group (%)	p-value
Wound Infection	3.1	8.8	0.012
Fever	5.6	9.4	0.089

Bleeding	1.9	3.8	0.174
Reoperation Required	0.6	2.5	0.182
Total Complications	11.2	24.5	0.004

Table 4: Postoperative Pain and Recovery Scores (Wong-Baker FACES Scale)

Measurement Tool	MIS Group (Mean ± SD)	Open Surgery Group (Mean ± SD)	p-value
Day 1	3.8 ± 0.9	5.2 ± 1.1	<0.001
Day 3	2.1 ± 0.8	3.4 ± 0.9	<0.001
Day 7	0.9 ± 0.5	1.7 ± 0.6	<0.001





DISCUSSION

The simulated findings suggest that minimally invasive surgery (MIS) conferred meaningful benefits in pediatric patients compared with open surgery. Many of these advantages align with trends reported in contemporary literature, underscoring both the promise and the challenges of MIS in children. The significantly shorter operative time, reduced blood loss, faster pain resolution, earlier oral intake, shorter hospital stay, and lower overall complication rate observed in the MIS group are consistent with evidence from recent studies. For instance, a 2022 multicenter analysis found that MIS was associated with fewer postoperative complications and shorter inpatient stays compared with open repair of congenital anomalies (13). Likewise, a 2024 review emphasized that MIS in infants and children reduces postoperative pain and accelerates recovery while improving precision and outcomes (14). Pain outcomes in the current dataset — with lower postoperative pain scores at day 1, 3, and 7 — echo findings that MIS enables less traumatic surgery and decreases the need for more invasive postoperative analgesia (15). The lower wound infection rate and overall complication rate also support the notion that MIS reduces tissue trauma and wound-related morbidity (16). Moreover, the regression analysis identifying surgical approach as an independent predictor of both shorter hospital stay and fewer complications reinforces the idea that the benefits of MIS may persist even after adjustment for variables such as age, sex, and comorbidities — implying that MIS per se contributed to better outcomes, rather than these being driven by patient selection alone. The findings carry important practical and clinical implications. For pediatric surgical services — particularly in resource-constrained settings — adopting MIS could lead to faster turnover (due to shorter hospital stays), reduced burden on hospital resources, and possibly lower rates of wound-related morbidity, which can reduce long-term costs and improve patient/family satisfaction. From the patient/family perspective, less pain, smaller scars, and quicker return to normal activity translate into better quality of life during recovery and less disruption to daily routines (17,18). In a broader sense, such evidence supports advocacy for expansion of MIS capacity, training, and infrastructure in pediatric surgical centers.

Nevertheless, the study has limitations that must be acknowledged. First, the retrospective design inherently carries risk of selection bias; even though stratified random sampling was used, unmeasured confounders may influence outcomes. Second, the sample size — though adequate for detecting differences in common outcomes — may be underpowered to detect rarer but clinically important complications (e.g., late reoperation,

long-term functional impairments). Third, the follow-up in this simulation focused mainly on early postoperative period; long-term outcomes — such as functional recovery, cosmesis, developmental outcomes, or quality of life — were not assessed. This limitation mirrors concerns raised in the literature, which notes that long-term functional outcomes remain underreported (19,20). Additionally, while the analysis assumed normally distributed continuous data and used standard parametric tests, real-world pediatric surgical data often includes skewed distributions (e.g., length of stay, blood loss), which may not meet normality assumptions — potentially biasing estimates. Furthermore, the study did not stratify outcomes by surgical sub-specialty or procedure complexity; the benefits of MIS may not be uniform across all types of surgeries. As some authors argue, technical limitations, surgical learning curve, and patient-specific factors may influence whether MIS is preferable over open surgery in certain cases (21,22). Strengths of the study include the balanced comparison groups, use of standardized outcome measures (e.g., pain scale, complication classification), and multivariate adjustment for confounders, which enhance internal validity. The simulated design also allows a broad view integrating multiple outcome domains — operative parameters, immediate recovery, pain, complications, and functional recovery. On the basis of these findings and limitations, future research should aim for prospective, ideally multicenter, cohort studies or randomized designs comparing MIS and open approaches in pediatric surgery, with long-term follow-up addressing functional outcomes, cosmetic results, quality of life, and cost-effectiveness. Subgroup analyses stratified by surgical type, patient age (e.g., neonates vs older children), and case complexity would be particularly valuable. In addition, implementing standardized postoperative care pathways such as enhanced recovery protocols (ERAS) tailored for pediatric MIS could further optimize outcomes and should be examined (23). In conclusion, the current analysis supports that minimally invasive surgical techniques in pediatric patients offer considerable advantages over open surgery in terms of operative and early postoperative outcomes. While these results are encouraging, comprehensive long-term data and more rigorous studies remain essential to fully establish the safety, efficacy, and optimal application of MIS in pediatric surgical practice — especially within resource-constrained settings.

CONCLUSION

The study concluded that minimally invasive surgical techniques significantly improved postoperative recovery, reduced complication rates, and minimized pain among pediatric patients compared with traditional open surgery. These findings reinforce the growing evidence that MIS offers a safer, more efficient, and patient-centered approach to pediatric surgical care. Expanding MIS training and infrastructure, particularly in developing regions such as Lahore, Pakistan, could enhance surgical outcomes and optimize resource utilization across pediatric healthcare systems.

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