ADVANCEMENTS IN MINIMALLY INVASIVE TECHNIQUES: EXPLORING THE BENEFITS AND CHALLENGES OF LAPAROSCOPIC AND ROBOTIC SURGERIES IN CHILDREN

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Minimally invasive surgery (MIS) has revolutionized pediatric surgical care by offering reduced trauma, faster recovery, and improved aesthetic outcomes compared to open procedures. This study explores recent advancements in laparoscopic and robotic surgeries in children, focusing on their clinical effectiveness, challenges, and statistical outcomes. A retrospective review of 4,240 pediatric cases revealed that while laparoscopy remains the predominant technique, robotic surgery is gaining traction due to its superior precision and ergonomic advantages. Despite longer operative times and higher costs, robotic-assisted procedures demonstrated lower complication rates, reduced postoperative pain, and greater parental satisfaction. These findings underscore the growing role of robotic surgery in complex pediatric cases and highlight the need for continued innovation and training in minimally invasive techniques.

Key words: Pediatric surgery, minimally invasive surgery, laparoscopy, robotic surgery, surgical outcomes, children, postoperative recovery, technological advancements, cost-effectiveness, surgical innovation.

Introduction. Minimally invasive surgery (MIS) has significantly transformed the field of pediatric surgery over the past few decades. The introduction of laparoscopic techniques in children marked a major milestone in reducing surgical trauma, postoperative pain, and recovery time, while improving cosmetic outcomes. More recently, robotic-assisted surgery has emerged as a cutting-edge approach, offering enhanced dexterity, three-dimensional visualization, and greater precision—features particularly valuable in complex pediatric cases.

While the advantages of MIS are well-documented in adult populations, its application in children presents unique challenges. Pediatric patients have smaller anatomical spaces, requiring highly specialized instruments and techniques. Additionally, the high cost and limited availability of robotic systems, coupled with the need for extensive training, have restricted their widespread adoption in pediatric surgical practice.

Nevertheless, there has been growing interest in integrating robotic platforms into pediatric surgery, especially for procedures that demand meticulous dissection and suturing, such as pyeloplasty and fundoplication. Comparative studies between laparoscopic and robotic approaches in children are still limited, and further research is needed to assess their relative benefits and limitations.

This study aims to evaluate current advancements in laparoscopic and robotic surgeries in pediatric populations. By analyzing a large cohort of surgical cases across multiple centers, we explore the clinical outcomes, benefits, and challenges associated with each technique, providing updated insights into their roles in modern pediatric surgical care.

Materials and methods. This retrospective, multicenter study was conducted to evaluate the outcomes of minimally invasive surgical techniques—specifically laparoscopic and robotic-assisted procedures—in pediatric patients. The study included data collected from five high-volume pediatric surgical centers located across Europe and Asia. Institutional review board (IRB) approval was obtained at each participating center, and the study adhered to the ethical standards of the Declaration of Helsinki.

The patient population consisted of children aged from newborn to 18 years who underwent either laparoscopic or robotic surgery between January 2017 and December 2023. Inclusion criteria encompassed common pediatric surgical procedures where both laparoscopic and robotic approaches were routinely utilized, including appendectomy, cholecystectomy, pyeloplasty, hernia repair, and Nissen fundoplication. Patients with incomplete medical records or who underwent emergency open surgery without a minimally invasive attempt were excluded from the analysis.

Data were extracted from electronic medical records and operative reports, and included demographic information (age, sex, weight), type of procedure performed, surgical technique used (laparoscopic or robotic), duration of the operation (measured from skin incision to closure), intraoperative complications, and any conversions to open surgery. Postoperative outcomes were also recorded, including length of hospital stay, pain scores assessed using age-appropriate pediatric pain scales (e.g., FLACC, Wong-Baker Faces), time to return to oral intake, and time to full recovery. Parental satisfaction was assessed through a standardized survey administered upon discharge and at follow-up.

Economic analysis was performed to estimate the average cost of each procedure type, including operative expenses, equipment use, and postoperative care. Where applicable, hospital billing records were used to determine the direct costs associated with each surgical method.

All statistical analyses were conducted using SPSS software (version 27.0; IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize baseline characteristics. Continuous variables were expressed as means with standard deviations, while categorical variables were presented as frequencies and percentages.

Comparative analyses between laparoscopic and robotic surgery groups were performed using independent t-tests for continuous variables and chi-square or Fisher's exact tests for categorical variables. Statistical significance was defined as a p-value of less than 0.05.

The aim of this methodology was to provide a comprehensive comparison of the two minimally invasive surgical modalities in pediatric populations across multiple institutions, reflecting real-world practices and outcomes. This approach allowed for the evaluation of not only clinical effectiveness and safety, but also logistical and economic feasibility, which are critical when considering broader implementation of advanced technologies such as robotic systems in pediatric surgery.

Results. A total of 4,240 pediatric patients were included in the final analysis, with 3,214 (75.8%) undergoing laparoscopic procedures and 1,026 (24.2%) undergoing robotic-assisted surgeries. The age range of the patients was from 2 months to 17 years, with a mean age of 8.6 ± 4.3 years. The overall male-to-female ratio was approximately 1.2:1. The most commonly performed procedures across both groups were appendectomy (28.3%), pyeloplasty (22.5%), cholecystectomy (18.1%), hernia repair (15.9%), and Nissen fundoplication (11.4%).

Operative time differed significantly between the two surgical techniques. The mean operative time for laparoscopic procedures was 68.4 ± 15.2 minutes, while robotic-assisted surgeries took longer on average, with a mean duration of 84.1 ± 17.6 minutes ($p < 0.01$). Despite the longer duration, robotic procedures demonstrated a lower rate of intraoperative complications. In the robotic group, intraoperative complications occurred in 2.6% of cases, compared to 4.1% in the laparoscopic group ($p = 0.04$). The rate of conversion to open surgery was also lower in the robotic group at 1.7%, compared to 3.2% in the laparoscopic cohort ($p = 0.03$).

Postoperative outcomes favored robotic surgery in several domains. The average length of hospital stay for robotic patients was 2.5 ± 1.1 days, compared to 2.9 ± 1.3 days in the laparoscopic group ($p = 0.04$). Pain levels, assessed using standardized pediatric pain scales 24 hours after surgery, were also significantly lower in the robotic group, with a mean pain score of 2.7 out of 10, compared to 3.4 in the laparoscopic group ($p < 0.05$). Additionally, robotic surgery patients resumed oral intake and returned to normal activity slightly faster, although these differences were not statistically significant.

Parental satisfaction was assessed at discharge and follow-up using a 5-point Likert scale, with scores converted into percentage satisfaction levels. In the laparoscopic group, 87% of parents reported being "very satisfied" or "satisfied" with the procedure and postoperative care, while this percentage rose to 93% in the robotic group. Notably, parents cited reduced scarring, quicker recovery, and better pain control as key factors contributing to their satisfaction with robotic surgery.

However, cost analysis revealed a substantial difference between the two modalities. Robotic procedures were, on average, 2.2 times more expensive than their laparoscopic counterparts. The increased cost was attributed to the robotic system's maintenance, disposable instruments, and longer operating room usage. While the higher cost limited the routine use of robotic surgery in some centers, in institutions with established robotic programs, the technology was increasingly being used for complex procedures such as pyeloplasty and redo surgeries, where its benefits in terms of precision and visualization were most apparent.

Overall, the results demonstrate that while robotic surgery may not yet be the standard for all pediatric minimally invasive procedures, it offers tangible advantages in selected cases. Its favorable outcomes in terms of reduced complications, better pain management, and higher satisfaction support its growing integration into pediatric surgical practice, provided that financial and logistical challenges can be addressed.

Conclusions. The findings of this multicenter study highlight the significant progress and growing potential of minimally invasive techniques in pediatric surgery. Laparoscopic surgery remains the most widely used approach due to its effectiveness, safety, and accessibility. However, robotic-assisted surgery is emerging as a valuable alternative, particularly in complex and delicate procedures where enhanced precision, superior visualization, and greater instrument dexterity offer clear clinical advantages.

Despite longer operative times and higher costs, robotic surgery demonstrated lower rates of intraoperative complications, reduced postoperative pain, shorter hospital stays, and higher parental satisfaction. These benefits suggest that, when available and economically feasible, robotic-assisted techniques may improve surgical outcomes and the overall patient and family experience.

Nevertheless, limitations such as high financial burden, limited pediatric-sized instruments, and the need for specialized training continue to challenge the broader implementation of robotic systems in pediatric care. Future efforts should focus on expanding access to robotic platforms, developing pediatric-specific technology, and conducting long-term, prospective studies to further validate their advantages.

In conclusion, both laparoscopic and robotic approaches have distinct strengths, and the choice of technique should be guided by the patient’s condition, surgical complexity, available resources, and institutional expertise. As technology continues to evolve, minimally invasive surgery will likely remain at the forefront of innovation in pediatric surgical care.

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