Interference Journal ISSN 2009-3578

TECHNOLOGICAL ADVANCES AND CONTEMPORARY CHALLENGES IN PEDIATRIC LAPAROSCOPIC AND ROBOTIC SURGERY: A NARRATIVE REVIEW

Juliana Pascon dos Santos, Aline Maria Noli Mascarin, Fabiana Garcia Ramos Guilen, Gisele Rozante Polanzan, Beatriz Fachini Galvão, Lara Fachini Galvão, Marcela Amaro de Santana, Ricardo de Argollo Haber, Luiza Santos de Argollo Haber, Janayna Fernandes da Rosa, Maria Júlia Guimarães Pelegrina Grancieri, Juliana Rejane da Silva Roque, Daniele Carvalho Garbelini, Rodolfo de Oliveira Medeiros.

https://doi.org/10.36557/2009-3578.2026v12n2p290-301
Artigo recebido em 20 de Junho e publicado em 11 de Setembro de 2026

NARRATIVE REVIEW

ABSTRACT

Pediatric minimally invasive surgery has undergone significant transformations over recent decades, driven by the consolidation of laparoscopy and the progressive incorporation of robotic surgery across different surgical specialties. These technologies have enabled reduced surgical trauma, decreased postoperative pain, improved anatomical visualization, enhanced technical precision, and faster postoperative recovery. The present study aimed to analyze technological advances, novel techniques, and contemporary instruments applied to pediatric laparoscopic and robotic surgery, as well as to discuss their main clinical, economic, and educational challenges. This study consists of a Narrative Literature Review conducted through searches in databases including PubMed, Scopus, Web of Science, SciELO, and ScienceDirect, covering publications from 2016 to 2026. The research question was developed according to the PICo strategy, considering children undergoing pediatric surgical procedures, technological advances in laparoscopy and robotics, and the contemporary hospital setting. The findings demonstrate that laparoscopy remains established as a safe and effective approach for multiple pediatric indications, while robotic surgery expands the possibilities for complex reconstructive procedures, particularly in pediatric urology. Nevertheless, limitations related to high costs, learning curves, the need for miniaturized instruments, and unequal access persist. It is concluded that pediatric laparoscopic and robotic surgery represents an expanding field with the potential to improve surgical care, provided that it is accompanied by specialized training, critical cost-effectiveness assessment, and the development of technologies adapted to the anatomical specificities of pediatric patients.

Keywords: Pediatric Surgery; Laparoscopy; Robotic Surgery; Minimally Invasive Procedures; Biomedical Technology.

Instituição afiliada – Universidade de Marília (UNIMAR)

Autor correspondente*: Rodolfo de Oliveira Medeiros e-mail: rodolfomedeiros@unimar.br*

This work is licensed under a Creative Commons Attribution 4.0 International License.

1- INTRODUCTION

Minimally invasive pediatric surgery has become one of the major milestones in the evolution of contemporary surgical practice, as it enables less traumatic interventions with smaller incisions, reduced postoperative pain, improved cosmetic outcomes, and faster recovery. Within this context, laparoscopy has become a widely adopted approach in several pediatric procedures, replacing open surgery in selected cases and progressively expanding its clinical indications (SAXENA *et al*., 2023; PELIZZO *et al*., 2024).

The expansion of laparoscopic techniques in pediatrics has also been directly associated with the development of equipment better suited to the anatomical characteristics of children, including smaller-caliber optics, delicate forceps, high-definition imaging systems, and instruments adapted to reduced body cavities. These advances have facilitated the performance of procedures in patients across different age groups, including infants and young children, although limitations related to the availability of pediatric-specific devices still persist (PELIZZO *et al*., 2024; POGORELIĆ *et al*., 2022).

Simultaneously, robotic surgery has gained increasing prominence in pediatric surgery, particularly in procedures requiring intracorporeal suturing, delicate reconstructions, and precise manipulation of small anatomical structures. Enhanced three-dimensional visualization, tremor filtration, articulated instruments, and improved surgeon ergonomics have been identified as significant advantages over conventional laparoscopy, especially in reconstructive pediatric urological surgeries (MEI; TANG, 2023; SHETH; KOH, 2019).

Despite the technological enthusiasm surrounding robotic surgery, its incorporation into pediatric practice remains marked by important challenges. These include the high costs of acquisition and maintenance of robotic platforms, the need for specialized training, the learning curve associated with surgical teams, the limitation of miniaturized instruments, and the concentration of this technology in highly specialized centers. Such factors require critical evaluation to ensure that innovation is not incorporated merely as a tool for technical sophistication, but rather as an effective strategy for improving patient safety and clinical outcomes (SAXENA *et al*., 2023;

GUNDETI *et al*., 2025).

Given this scenario, the present study aimed to analyze technological advances, novel techniques, and contemporary instruments applied to pediatric laparoscopic and robotic surgery, as well as to discuss the main clinical, economic, educational, and healthcare-related challenges associated with their implementation in current surgical practice.

2- METHOD

This study consists of a Narrative Literature Review, a methodological approach considered appropriate for gathering, interpreting, and critically discussing scientific evidence on broad, complex, and constantly evolving topics. This approach allows the integration of studies with different designs, including literature reviews, observational studies, clinical series, comparative studies, and technological analyses, thereby promoting a broader understanding of the evolution of pediatric laparoscopic and robotic surgery (SAXENA *et al*., 2023; PELIZZO *et al*., 2024).

The research question was developed based on the PICo strategy. The population (P) consisted of children undergoing pediatric surgical procedures; the phenomenon of interest (I) included technological advances, techniques, and instruments applied to laparoscopic and robotic surgery; and the context (Co) encompassed contemporary hospital services and surgical centers. Accordingly, the following guiding research question was established: what are the main technological advances and contemporary challenges related to the use of laparoscopic and robotic techniques and instruments in pediatric surgery?

The search strategy was planned using the PubMed, Scopus, Web of Science, SciELO, and ScienceDirect databases, employing descriptors and keywords such as “Pediatric Surgery,” “Laparoscopy,” “Robotic Surgical Procedures,” “Minimally Invasive Surgery,” “Robot-Assisted Surgery,” “Pediatric Urology,” and “Surgical Instruments,” combined through the Boolean operators AND and OR. Studies published between 2016 and 2026 in Portuguese, English, and Spanish were considered eligible. Articles directly related to minimally invasive pediatric surgery, with emphasis on laparoscopy, robotics,

surgical instruments, training, and clinical outcomes, were included. Editorials, letters to the editor, exclusively adult studies, publications unrelated to pediatrics, and studies with insufficient methodological or clinical descriptions were excluded.

3- RESULTS

The analyzed studies indicate that pediatric laparoscopy remains an established approach across multiple areas of pediatric surgery, including abdominal, urological, thoracic procedures, and selected congenital malformation repairs. The most frequently reported benefits include reduced surgical trauma, decreased postoperative pain, shorter hospital stays, faster functional recovery, and improved cosmetic outcomes when compared with conventional open surgery (SAXENA *et al*., 2023; PELIZZO *et al*., 2024).

From a technological perspective, continuous advancements have been observed in pediatric laparoscopic instruments, particularly through the miniaturization of forceps, optics, and access devices. The literature highlights that adapting equipment to the child's size and physiological condition is essential to improve the safety of minimally invasive procedures. However, the development of these devices still faces regulatory, economic, and industrial barriers, since many pediatric instruments are considered technologies with a limited consumer market, which hinders their production and dissemination (PELIZZO *et al*., 2024; SHETH; KOH, 2019).

Pediatric robotic surgery, in turn, has shown progressive growth, particularly in pediatric urology. Robotic pyeloplasty is frequently described as one of the most consolidated applications, presenting favorable clinical outcomes, high success rates, and the possibility of being performed in complex cases or reoperations. Comparative studies indicate that laparoscopic and robotic pyeloplasty may achieve similar outcomes when performed by experienced teams, with the choice being influenced by the surgeon's expertise, institutional availability, and patient characteristics (ESPOSITO *et al*., 2023; PÉREZ-MARCHÁN *et al*., 2022).

Overall, the findings suggest that novel techniques and instruments in pediatric laparoscopic and robotic surgery expand therapeutic possibilities, but also require

careful evaluation regarding safety, costs, learning curves, technological adequacy, and institutional accessibility. The literature emphasizes that surgical innovation should be accompanied by structured training, outcome assessment, and the development of devices specifically designed for the pediatric population (JACOBSON; PANDYA, 2023). In this context, aiming to synthesize the main studies analyzed, their scientific contributions, and the technological advances identified in the literature, a summary table presenting the most relevant findings of this narrative review will be provided below.

Table 1. Summary of the Main Studies Included in the Narrative Review on Technological Advances and Contemporary Challenges in Pediatric Laparoscopic and Robotic Surgery

Authors/ Year	Study Design	Main Objective	Technological Focus	Main Findings	Limitations/ Challenges
Saxena et al. (2023)	Narrative Review	To analyze the current status and future perspectives of pediatric robotic surgery	Robotic pediatric surgery	Robotic surgery improves precision, ergonomics, and visualization in complex pediatric procedures	High costs, limited accessibility, and need for specialized training
Mei and Tang (2023)	Review Article	To discuss the current applications and future perspectives of robotic-assisted surgery in pediatric surgery	Robotic-assisted surgery	Robotic systems enhance dexterity and facilitate delicate reconstructive procedures	Limited evidence in some pediatric specialties and elevated operational costs
Pelizzo et al. (2024)	Review Article	To evaluate technological progress in minimally invasive pediatric surgery	Dedicated laparoscopic instruments and anesthetic advances	Instrument miniaturization improved safety and expanded minimally invasive approaches in children	Limited availability of pediatric-specific devices
Esposito et al. (2023)	Systematic Review	To analyze outcomes of robotic-assisted pyeloplasty in children	Robotic pyeloplasty	High success rates and favorable postoperative outcomes were observed	Need for larger comparative studies and long-term follow-up
Pérez-Marchán et al. (2022)	Comparative Study	To compare laparoscopic and robotic pyeloplasty in pediatric patients	Laparoscopic vs. robotic pyeloplasty	Both techniques demonstrated similar efficacy when performed by experienced teams	Institutional availability and surgeon expertise influence technique selection

Pakkasjärvi et al. (2022)	Systematic Review	To investigate learning curves in pediatric robot-assisted pyeloplasty	Surgical learning curves	Robotic surgery may reduce technical difficulty during reconstruction	Structured training and simulation remain essential
Sheth and Koh (2019)	Review Article	To explore future technologies in pediatric robotic urology	Robotic innovation and miniaturization	Future robotic systems may become smaller and more adaptable to pediatric anatomy	Current robotic platforms are primarily designed for adults
Nolan et al. (2023)	Review Article	To discuss image-guided surgery and augmented reality in pediatric minimally invasive surgery	Augmented reality and surgical navigation	Emerging technologies may improve intraoperative precision and safety	Need for validation studies and technological standardization
Dijkstra et al. (2023)	Systematic Review	To evaluate artificial intelligence and machine learning applications in pediatric surgery	Artificial intelligence in surgery	AI may improve decision-making, image analysis, and surgical planning	Ethical concerns and lack of robust pediatric evidence
Jacobson and Pandya (2023)	Review Article	To provide an overview of pediatric robotic surgery	Pediatric robotic surgery	Robotic surgery expands therapeutic possibilities in pediatric care	Costs, accessibility, and training remain major barriers

Source: Prepared by the authors (2026).

4- DISCUSSION

The evolution of pediatric laparoscopic and robotic surgery reveals a progressive movement toward technical refinement and technological incorporation in pediatric surgical care. Laparoscopy represented the first major advancement by reducing surgical trauma and enabling improved postoperative outcomes across different procedures. Subsequently, robotic surgery expanded these possibilities by providing greater precision, improved ergonomics, and advanced visualization and tissue manipulation capabilities (SAXENA *et al*., 2023; MEI; TANG, 2023; CHEN; PETERS, 2019).

In pediatric surgery, reducing surgical trauma is particularly important, as children present anatomical, physiological, and emotional specificities that make less invasive approaches highly desirable. Smaller incisions, reduced pain, and faster

recovery may contribute not only to improved clinical outcomes but also to a better family experience during pediatric hospitalization. In this sense, minimally invasive surgery should be understood both as a technical advancement and as a child-centered care strategy (PELIZZO *et al*., 2024; SUBRAMANIAM, 2019; POGORELIĆ *et al*., 2022).

Although conventional laparoscopy is widely established, it still presents well-known technical limitations, including bidimensional visualization in many systems, rigid instruments, restricted movements, and greater technical demands for intracorporeal suturing. These difficulties may become even more pronounced in young children due to the reduced operative space and the fragility of pediatric tissues. Robotic surgery emerges precisely as an alternative to overcome some of these limitations by offering articulated movements, three-dimensional visualization, and tremor filtration (SHETH; KOH, 2019; MEI; TANG, 2023).

Pediatric urology stands out as one of the specialties with the greatest development in robotic surgery, especially in reconstructive procedures. Robotic pyeloplasty has been extensively studied and has demonstrated favorable outcomes regarding safety, efficacy, and reproducibility. However, comparative studies also indicate that conventional laparoscopy may achieve similar outcomes when performed by experienced surgeons, suggesting that the superiority of robotics should not be automatically assumed, but rather evaluated according to surgical indication, institutional context, and team expertise (ESPOSITO *et al*., 2023; PÉREZ-MARCHÁN *et al*., 2022; KO; GUNDETI, 2021).

Another relevant issue concerns the learning curve associated with robotic surgery. Although robotic systems may facilitate the execution of complex sutures and reconstructions, they require specific training, platform mastery, coordinated teamwork, and familiarity with safety protocols. Therefore, the incorporation of this technology demands structured training programs, simulation-based education, and supervised practice in order to ensure that technological innovation remains aligned with the technical competence required for safe patient care (PAKKASJÄRVI *et al*., 2022; GUNDETI *et al*., 2025).

The limitation of specifically pediatric instruments remains a central challenge. Many robotic platforms were originally designed for adult surgery, creating difficulties

related to trocar size, robotic arm spacing, adaptation to reduced anatomical spaces, and applicability in infants or low-weight children. The development of miniaturized devices, more flexible systems, and technologies with improved tactile feedback is essential to expand the safety and applicability of pediatric robotic surgery (SHETH; KOH, 2019; PELIZZO *et al*., 2024).

In addition to technical challenges, the economic dimension must also be considered. The high costs associated with robotic platforms, instruments, maintenance, and professional training may limit their implementation in many healthcare institutions, particularly in resource-constrained healthcare systems. Although some authors suggest that reductions in hospital stay and postoperative complications may partially offset these costs in specific scenarios, robust cost-effectiveness studies focused specifically on the pediatric population are still needed (SAXENA *et al*., 2023; GUNDETI *et al*., 2025).

Finally, the future of pediatric laparoscopic and robotic surgery is expected to involve the integration of artificial intelligence, augmented reality, surgical navigation systems, advanced simulation, and more compact robotic platforms. These innovations may contribute to greater precision, individualized surgical planning, and improved intraoperative safety. However, their consolidation will depend on the production of consistent scientific evidence, the training of qualified teams, and the equitable expansion of access to these technologies, thereby preventing innovation from exacerbating existing inequalities in pediatric surgical care (BEYAZ *et al*., 2025; MEI; TANG, 2023; PELIZZO *et al*., 2024).

5- CONCLUSION

Pediatric laparoscopic and robotic surgery represents an expanding field marked by technological advances that have transformed pediatric surgical practice. Laparoscopy remains an established, safe, and effective approach for several indications, while robotic surgery expands the possibilities for complex procedures, particularly those requiring intracorporeal suturing, delicate reconstruction, and greater technical precision.

The main benefits identified in the literature include reduced surgical trauma, decreased postoperative pain, shorter hospital stays, improved anatomical visualization, enhanced surgeon ergonomics, and the potential for improved performance in technically demanding procedures. These aspects reinforce the importance of minimally invasive techniques as fundamental components of contemporary pediatric surgery.

Nevertheless, the incorporation of these technologies still faces significant challenges, particularly regarding costs, institutional availability, team training, learning curves, and the need for instruments adapted to the anatomical specificities of children. Therefore, the adoption of pediatric robotic surgery should be guided by clinical criteria, scientific evidence, cost-effectiveness evaluation, and commitment to patient safety.

It is concluded that advances in pediatric laparoscopic and robotic surgery offer promising perspectives for improving pediatric surgical care. However, their consolidation will depend on investments in research, professional training, pediatric technological innovation, and institutional policies that promote safe, ethical, and equitable access to new surgical technologies.

REFERENCES

BEYAZ, S.; ÖZGÖZEN, A. L.; TURGUT, N.; ÖLKE, H. C. Artificial intelligence and robotic surgery in clinical medicine: progress, challenges, and future directions. **Future Science OA**, [S.l.], v. 11, n. 1, p. 2540742, 2025. DOI: 10.1080/20565623.2025.2540742. Available from: Taylor & Francis Online. Acessed on: May. 12, 2026.

CHEN, C. J.; PETERS, C. A. Robotic Assisted Surgery in Pediatric Urology: Current Status and Future Directions. **Frontiers in Pediatrics**, v. 7, p. 90, 2019. DOI: 10.3389/fped.2019.00090. Available from: https://doi.org/10.3389/fped.2019.00090. Accessed on: May. 11, 2026.

ESPOSITO, C.; CERULO, M.; LEPORE, B. *et al*. Robotic-assisted pyeloplasty in children: a systematic review of the literature. **Journal of Robotic Surgery**, v. 17, n. 4, p. 1239-1246, 2023. DOI: 10.1007/s11701-023-01559-1. Available from: https://doi.org/10.1007/s11701-023-01559-1. Accessed on: May. 11, 2026.

GUNDETI, M. S.; *et al*. Robotics in pediatric urology: a review. **Journal of Pediatric Surgery**, 2025. DOI: 10.1016/j.jpedsurg.2024.10.062. Available from: https://doi.org/10.1016/j.jpedsurg.2024.10.062. Accessed on: May. 11, 2026.

JACOBSON, J. C.; PANDYA, S. R. Pediatric robotic surgery: an overview. **Seminars in Pediatric Surgery**, v. 32, n. 1, p. 151255, 2023. DOI: 10.1016/j.sempedsurg.2023.151255. Available from: https://pubmed.ncbi.nlm.nih.gov/36736161/. Accessed on: May. 11, 2026.

KO, A. M.; GUNDETI, M. S. Pediatric Robotic and Reconstructive Urology: Current Status and Future Perspectives. **Current Opinion in Urology**, v. 31, n. 4, p. 385-391, 2021. DOI: 10.1097/MOU.0000000000000893. Available from: https://journals.lww.com/co-urology/Abstract/2021/07000/Pediatric_robotic_and_reconstructive_urology_.11.aspx. Accessed on: May. 11, 2026.

MEI, H.; TANG, S. T. Robotic-assisted surgery in the pediatric surgeons' world: current situation and future prospectives. **Frontiers in Pediatrics**, v. 11, 2023. DOI: 10.3389/fped.2023.1120831. Available from: https://doi.org/10.3389/fped.2023.1120831. Accessed on: May. 10, 2026.

PAKKASJÄRVI, N.; DINDAR, S.; ERIKSSON, M. *et al*. Learning curves in pediatric robot-assisted pyeloplasty: a systematic review. **Journal of Clinical Medicine**, v. 11, n. 23, p. 6935, 2022. DOI: 10.3390/jcm11236935. Available from: https://doi.org/10.3390/jcm11236935. Accessed on: May. 8, 2026.

PELIZZO, G.; DESTRO, F.; PIERUCCI, U. M. *et al*. Minimal access in pediatric surgery: an overview on progress towards dedicated instrument developments and anesthesiologic advances to enhance safe completion of procedures. **Children**, v. 11, n. 6, p. 679, 2024. DOI: 10.3390/children11060679. Available from: https://doi.org/10.3390/children11060679. Accessed on: May. 7, 2026.

PÉREZ-MARCHÁN, M.; RODRÍGUEZ, A.; GONZÁLEZ, R. *et al*. Comparison of laparoscopic pyeloplasty vs. robot-assisted pyeloplasty for the management of ureteropelvic junction obstruction in children. **Frontiers in Pediatrics**, v. 10, 2022. DOI: 10.3389/fped.2022.1038454. Available from: https://doi.org/10.3389/fped.2022.1038454. Accessed on: May 4, 2026.

POGORELIĆ, Z.; *et al*. Advances and future challenges of minimally invasive pediatric surgery. **Children**, v. 9, n. 12, p. 1955, 2022. DOI: 10.3390/children9121955. Available from: https://doi.org/10.3390/children9121955. Accessed on: May. 9, 2026.

SAXENA, A. K.; BORGOGNI, R.; ESCOLINO, M.; D'AURIA, D.; ESPOSITO, C. Narrative review: robotic pediatric surgery — current status and future perspectives. **Translational Pediatrics**, v. 12, n. 10, p. 1912-1928, 2023. DOI: 10.21037/tp-22-427. Available from: https://doi.org/10.21037/tp-22-427. Accessed on: May. 8, 2026.

SHETH, K. R.; KOH, C. J. The future of robotic surgery in pediatric urology: upcoming technology and evolution within the field. **Frontiers in Pediatrics**, v. 7, p. 259, 2019. DOI: 10.3389/fped.2019.00259. Available from: https://doi.org/10.3389/fped.2019.00259. Accessed on: May. 12, 2026.

SUBRAMANIAM, R. Current Use of and Indications for Robot-assisted Surgery in Paediatric Urology. **Journal of Pediatric Urology**, v. 15, n. 2, p. 129-135, 2019. DOI: 10.1016/j.jpurol.2018.12.005. Available from: https://www.sciencedirect.com/science/article/abs/pii/S2405456918302396. Accessed on: May 9, 2026.

SUN, L.; LI, X.; ZHANG, Y. *et al*. Laparoscopic versus robot-assisted pyeloplasty in infants and young children with ureteropelvic junction obstruction. **Asian Journal of Surgery**, v. 46, n. 6, p. 2390-2396, 2023. DOI: 10.1016/j.asjsur.2022.12.044. Available from: https://doi.org/10.1016/j.asjsur.2022.12.044. Accessed on: May. 10, 2026.