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ANALYSIS OF BENEFITS AND CHALLENGES IN MINIMALLY INVASIVE PEDIATRIC SURGERY BASED ON THE PRISMA METHODOLOGY

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The purpose of the study was to assess the current status and future potential of minimally invasive surgery in pediatric practice, focusing on its application in congenital anomalies and pediatric oncology, and explores the benefits, challenges, and advances in minimally invasive surgery, with an emphasis on laparoscopic and thoracoscopic techniques. This review explores their current applications and future potential in treating congenital anomalies and pediatric cancers. A systematic analysis of studies from 2009 to 2024, drawn from major medical databases, highlights the advantages of laparoscopic and thoracoscopic approaches, including shorter hospital stays, reduced tissue damage, and improved cosmetic results. The authors stress that minimally invasive techniques are increasingly used in pediatric surgery for their ability to minimize trauma and accelerate recovery. They indicated the challenges are still present such as the requirement for specialized tools, high technical expertise, and the anatomical complexity of young patients. The review also examines emerging technologies like robotic-assisted systems and artificial intelligence, which may enhance surgical precision and patient safety. ption in pediatric practice can occur. The basic conclusion is done that minimally invasive surgery will become more accessible and effective for paediatrics with modern technology development and additional clinical researches.

Keywords: pediatric surgery, laparoscopy, thoracoscopy, robotic surgery, pediatric oncology, congenital anomalies.

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АНАЛІЗ ПЕРЕВАГ І ВИКЛИКІВ У МАЛОІНВАЗИВНІЙ ДИТЯЧІЙ ХІРУРГІЇ НА ОСНОВІ МЕТОДИКИ PRISMA

Метою дослідження було оцінка поточного стану та майбутнього потенціалу малоінвазивної хірургії в педіатричній практиці, зосереджуючись на її застосуванні при вроджених аномаліях та дитячій онкології, а також дослідження переваги, проблем та досягнень малоінвазивної хірургії з акцентом на лапароскопічні та торакоскопічні методи. У цьому огляді досліджено їх сучасне застосування та майбутній потенціал у лікуванні вроджених аномалій і дитячих онкологічних захворювань. Систематичний аналіз досліджень з 2009 по 2024 рік, взятих з основних медичних баз даних, висвітлює переваги лапароскопічного і торакоскопічного підходів, включаючи коротші терміни перебування в лікарні, зменшення пошкодження тканин і кращі косметичні результати. Автори наголошують на все більш частому застосуванні малоінвазивним методів в дитячій хірургії завдяки їхній здатності мінімізувати травми та прискорити одужання пацієнтів. Вони засвідчують наявність проблем, таких як потреба в спеціалізованих інструментах, висока технічна кваліфікація і анатомічна складність молодих пацієнтів. В огляді також розглядаються нові технології, такі як роботизовані системи та штучний інтелект, які можуть підвищити точність хірургічного втручання та безпеку пацієнтів. В якості провідного висновку автори прогнозують більшу доступність та ефективність малоінвазивної хірургії для педіатрії з розвитком сучасних технологій та додатковими клінічними дослідженнями.

Ключові слова: дитяча хірургія, лапароскопія, торакоскопія, роботизована хірургія, дитяча онкологія, вроджені аномалії.

The study is a fragment of the research project "Comorbidity in internal medicine clinics and in family medicine practice: characteristics of disease progression, strategies for providing medical care in times of global civilisational challenges", state registration No. 0123U100061.

Minimally invasive surgery (MIS), encompassing techniques such as laparoscopy and thoracoscopy, has emerged as a transformative approach in the surgical management of a diverse array of pathologies in adults over the past decade [27, 29, 35]. Its adoption in paediatric surgery, while showing remarkable progress, remains a relatively underexplored domain due to the distinct anatomical, physiological, and technical considerations inherent to the paediatric population [15, 17, 44]. The smaller body size, delicate tissues, and ongoing developmental processes in children necessitate a tailored approach to MIS, distinguishing it from its application in adults. In paediatric practice, MIS is employed to address a wide spectrum of conditions, including congenital anomalies such as oesophageal atresia, congenital diaphragmatic hernias, and genitourinary malformations, as well as oncological conditions like nephroblastoma and neuroblastoma [6, 39, 42]. The benefits of MIS, which include reduced tissue trauma, shorter hospital stays, enhanced cosmetic outcomes, and a lower incidence of postoperative complications, are particularly advantageous in children, where minimizing surgical invasiveness is of paramount importance to support growth, development, and long-term quality of life [8, 14, 41, 46].

Despite these advantages, the implementation of MIS in paediatric surgery is not without significant challenges [37]. The confined working space within the small anatomical structures of infants and young children demands exceptional precision and dexterity from surgeons. Furthermore, the need for specialized, size-appropriate equipment – such as miniaturized endoscopes, instruments, and imaging systems – adds a layer of complexity to the adoption of MIS in this population. The technical expertise required to perform these procedures is substantial, as surgeons must navigate the intricacies of paediatric anatomy while maintaining the high standards of safety and efficacy that MIS demands [1, 7, 21, 28]. The physiological differences in children, such as their unique metabolic rates, lower tolerance for blood loss, and immature organ systems, require careful perioperative management to optimize outcomes [10]. The learning curve for paediatric MIS is steep, and training programs must be robust to equip surgeons with the skills necessary to overcome these challenges. Moreover, the evidence base for MIS in paediatrics, while growing, remains limited compared to adult surgery, necessitating further research to establish standardized protocols and long-term outcomes [31]. As the field continues to evolve, advancements in technology, such as robotic-assisted surgery and improved imaging modalities, hold promise for further enhancing the safety and efficacy of MIS in paediatric patients, potentially broadening its applicability to even more complex conditions.

In addition, clinical outcomes of MIX in paediatric practice vary depending on the type of pathology, patient age, and the experience of the surgical team. Recent advances, such as the use of robotic systems and three-dimensional imaging, open up new prospects for improving the accuracy and safety of procedures, but their availability and effectiveness in paediatric surgery require further study [32, 34].

The purpose of the study was to assess the current status and future potential of minimally invasive surgery in pediatric practice, focusing on its application in congenital anomalies and pediatric oncology, and explore the benefits, challenges, and advances in minimally invasive surgery, with an emphasis on laparoscopic and thoracoscopic techniques.

Protocol and Registration.

A systematic approach to searching, selecting and analysing literature was used to prepare this review article in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The PRISMA methodology ensures transparency, reproducibility and structure in the data collection process, minimising bias and guaranteeing a high-quality review. The search stages, inclusion and exclusion criteria, article selection process, and data analysis methods are described in detail below.

Formulation of the research question.

The study is based on the following question, formulated according to the PICO (Population, Intervention, Comparison, Outcome) structure:

Population – Children (aged 0 to 18 years) with congenital anomalies or oncological diseases requiring surgical intervention.

Intervention – Minimally invasive surgical techniques, including laparoscopy and thoracoscopy.

Comparison – Traditional open surgical methods or no comparison (in the case of MIH assessment only).

Outcome – Clinical outcomes (surgical success, length of hospital stay, frequency of complications, cosmetic results), technical challenges (equipment limitations, complexity of performance) and prospects for development (innovative technologies).

Literature search strategy.

The literature search was conducted in electronic databases, which are the main sources of medical and scientific publications, in particular: PubMed/MEDLINE (to cover a wide range of clinical studies); Scopus (for interdisciplinary and citation data); Web of Science (for high-quality peer-reviewed articles); Cochrane Library (for systematic reviews and meta-analyses); Google Scholar (to identify additional sources, including grey literature). In addition, a manual search was conducted in the reference lists of key articles, and thematic issues of journals specialising in paediatric surgery and minimally invasive techniques were reviewed.

Search queries were developed using controlled vocabularies (e.g., MeSH in PubMed) and free-text terms to ensure maximum coverage of relevant publications. The main categories of search terms included: Population: “pediatric”, “children”, “neonate”, “infant”, “adolescent”; Intervention: “minimally invasive surgery”, “laparoscopy”, “thoracoscopy”, “endoscopic surgery”, “robotic surgery”; Pathologies: “congenital anomalies”, “congenital malformations”, “pediatric oncology”, “neuroblastoma”, “Wilms tumor”, “esophageal atresia”, ”diaphragmatic hernia”, “urological malformations”; Results: “clinical outcomes", "complications", "recovery time", "hospital stay", "cosmetic outcomes", "technical challenges", "innovations". The terms were combined using Boolean operators (AND, OR, NOT) to create complex search queries. For example, a typical query in PubMed looked like this: ("pediatric" OR "children" OR "neonate" OR "infant") AND ("minimally invasive surgery" OR 'laparoscopy' OR "thoracoscopy") AND ("congenital anomalies" OR "pediatric oncology" OR "neuroblastoma" OR "esophageal atresia") AND ("clinical outcomes" OR "technical challenges" OR "complications"). The search was limited to articles published between 2009–2025 to cover recent advances in MIS, given the rapid development of technology. The language of publications was limited to English, but relevant articles in other languages (with English abstracts) were also considered.

Inclusion and exclusion criteria.

To ensure the relevance and quality of the selected sources, clear inclusion and exclusion criteria were established. The inclusion criteria are articles describing the use of laparoscopy, thoracoscopy or other minimally invasive techniques in paediatric surgery, studies related to congenital anomalies (e.g. oesophageal atresia, diaphragmatic hernias, genitourinary system defects) or oncological diseases in children (e.g., nephroblastoma, neuroblastoma). The types of studies were randomised controlled trials, cohort studies, retrospective analyses, systematic reviews, meta-analyses, and clinical guidelines. Articles containing data on clinical outcomes (surgical success, complications, recovery time), technical challenges, or prospects for the development of minimally invasive surgery.

Exclusion criteria were articles relating exclusively to adult patients or mixed groups without separate analysis of the paediatric cohort, studies not related to laparoscopy or thoracoscopy (e.g. exclusively open surgery), non-clinical studies (laboratory, animal experiments), articles without clear data on clinical outcomes or technical aspects. Conference abstracts, letters to the editor, comments without primary data, and publications of low methodological quality (e.g., without clear methodology or statistics) were also not considered.

Article selection process.

Articles were selected in four stages in accordance with PRISMA recommendations. Identification – an initial set of publications was collected based on database search queries. Additional sources were identified through manual searches in reference lists and thematic journals. Screening – after removing duplicate titles and abstracts, articles were checked for compliance with the inclusion criteria. Articles that clearly did not correspond to the topic (e.g., concerned adults) were excluded. Suitability assessment – full-text versions of potentially relevant articles were analysed for compliance with the inclusion criteria. At this stage, articles with insufficient information or low quality were excluded. Inclusion – articles that passed all selection stages were included in the final analysis.

Risk of Bias in Individual Studies.

Risk of bias was assessed using tools tailored to study design: the Cochrane Risk of Bias tool for RCTs, the Newcastle-Ottawa Scale for cohort studies, and the AMSTAR-2 checklist for systematic reviews. This evaluation provided context for evidence quality, though detailed findings are not reported here given the review's narrative focus.

Ethical Considerations.

This article is a narrative review based solely on the analysis of previously published studies. No new clinical data were collected, and therefore ethical approval and patient consent were not required. Where applicable, the methodological quality of the included systematic reviews was assessed using AMSTAR-2, and the risk of bias was evaluated with the ROBIS tool to ensure the reliability of the evidence base.

A systematic literature review conducted in accordance with PRISMA guidelines allowed us to summarise current data on the use of minimally invasive surgical techniques, in particular laparoscopy and thoracoscopy, in paediatric surgery for the correction of congenital anomalies and the treatment of cancer in children.

Retrospective cohort study Sule Yalcin (2024) compared thoracoscopic versus open repair of esophageal atresia with tracheoesophageal fistula (EA/TEF) in 104 neonates treated between 2000 and 2020 [47]. The majority had Type C EA/TEF (97.1 %). Thoracoscopic repair, performed in 47.1 % of cases, was associated with significantly shorter postoperative ventilation duration and hospital stay (p=0.026, p=0.029, respectively). However, it was also linked to a higher incidence of anastomotic strictures (p=0.012). Rates of anastomotic leak, time to oral feeding, and recurrent TEF were similar between groups. Long-term tube feeding was less common in the thoracoscopy group by year three (p=0.032). These findings suggest that thoracoscopic repair is a safe and effective alternative to open surgery, with advantages in early recovery, despite an increased risk of stricture formation.

Adrian Surd et al. provide a comprehensive review of minimally invasive surgery for esophageal atresia and tracheoesophageal fistula, focusing on its evolution, current practices, and outcomes [40]. It highlights the advantages of thoracoscopic repair over open surgery, including similar success rates (85–95 %), shorter recovery times, less postoperative pain, and fewer musculoskeletal complications. The article emphasizes that MIS offers significant benefits in selected cases, though it remains technically demanding and requires specialized expertise and resources.

König T. et al. discussed the use of the telemedical platform TIC-PEA as a tool to support surgeons in performing minimally invasive surgery for esophageal atresia [18]. The study compares the frequency of MIS among patients who received telemedical consultation with a historical control group and evaluates associated complications, technical feasibility, and the role of telementoring. The results show that MIS was performed four times more often in the TIC-PEA group, despite these patients having a higher rate of complex conditions, including long-gap EA, isolated atresia, and associated anomalies such as VACTERL. The article emphasizes several advantages of MIS: reduced surgical trauma, better conditions for video-based consultation and training, and improved preoperative planning. Intraoperative images and videos could be reviewed in real-time, enabling expert feedback and contributing to improved surgical outcomes. This approach was particularly beneficial in complex cases where delayed primary repair was required. Although most patients were included after the initial surgery, telementoring was still valuable in guiding the management of complications. The author highlights that while telementoring cannot replace formal surgical training, it provides a national digital support network for discussing treatment plans, identifying potential pitfalls, and facilitating patient transfers when necessary. The article concludes that although MIS for EA remains underused in Germany, combining it with structured telementoring is a promising strategy to enhance the safety, effectiveness, and quality of care for children with rare congenital anomalies.

Rideout & ulkan analyse the possibilities, advantages, limitations and technical features of thoracoscopic treatment of congenital diaphragmatic hernia (CDH) in newborns [38]. Traditionally, CDH is treated with open surgery via laparotomy, but in recent years, minimally invasive techniques, including thoracoscopy, have been actively introduced into clinical practice. The authors note that although MIS has significant advantages – less pain, faster recovery, shorter ventilation and hospitalisation times, and better cosmetic results – its use in the neonatal period is controversial due to the risks of hypothermia and metabolic acidosis caused by CO_2 insufflation. The article pays particular attention to the selection of patients for thoracoscopy. The authors include stable cardiorespiratory status, small defect size (types A or B), intra-abdominal location of the stomach, and no need for plastic closure of the defect among the safety criteria for MIS. If the use of a synthetic patch is anticipated (e.g., for large defects), MIS may be replaced or supplemented by minimal thoracotomy. The paper describes in detail the technique of the intervention, including patient positioning, trocar positions, choice of instruments (preference is given to 3–5 mm instruments), insufflation conditions (low pressure 4–6 mm Hg, low flow), defect suturing technique, and the importance of drainage. The role of the multidisciplinary team is considered separately, with the anaesthesiologist playing a key role in maintaining ventilation and avoiding barotrauma of the hypoplastic lungs. In the postoperative period, patients are monitored in intensive care. Thanks to MIS, there is a faster transition to independent breathing, early restoration of nutrition, and less use of narcotic analgesics, although the risk of hernia recurrence is higher than with open surgery, so long-term clinical and radiological monitoring is necessary. Authors emphasise that thoracoscopy is a safe method in carefully selected newborns, with pulmonary hypoplasia being the main limitation.

This systematic review and meta-analysis Abdulkreem Aljuhani et al. evaluated and compared the outcomes of thoracoscopic versus open surgical repair in children with congenital diaphragmatic hernia, synthesizing data from 35 studies involving 1680 patients [2]. The analysis revealed that the thoracoscopic approach is associated with several clinically significant advantages, including a markedly shorter hospital stay, reduced duration of postoperative mechanical ventilation, and a lower overall mortality rate, indicating its potential to facilitate faster recovery and improve survival in appropriately selected pediatric patients. These benefits are attributed to the minimally invasive nature of thoracoscopic surgery, which allows for enhanced visualization, decreased surgical trauma, and quicker physiological stabilization postoperatively. However, the thoracoscopic approach was also associated with certain limitations, including significantly longer operative times and a higher risk of hernia recurrence, which may be related to technical challenges such as limited working space, steep learning curves, and difficulties in achieving adequate suture tension and diaphragmatic rim mobilization. Additionally, thoracoscopic procedures demonstrated lower intraoperative pH and elevated PCO_2 levels, underscoring the physiological impact of

CO_2 insufflation and the need for meticulous intraoperative monitoring and anesthetic management. While the findings suggest thoracoscopy as a viable and advantageous alternative to open repair in selected patients, the predominance of observational data and methodological heterogeneity across included studies highlight the need for future large-scale randomized controlled trials to validate these outcomes and establish standardized criteria for surgical decision-making in CDH management.

A. Garzi presents a retrospective evaluation of the effectiveness and safety of minimally invasive treatment of urolithiasis in children using flexible ureterorenoscopy (FURS) and laser lithotripsy (FURSL) [13]. Conducted between 2017 and 2019, the study analyzed 21 procedures in 17 pediatric patients aged 2 to 18 years. The majority of patients had underlying urinary tract or metabolic abnormalities, such as hypercalciuria, distal renal tubular acidosis, or anatomical malformations like hydronephrosis and double renal systems. The study highlights that Retrograde Intrarenal Surgery (RIRS) with FURS or FURSL enables direct visualization and effective fragmentation of kidney and ureteral stones. It shows a significant reduction in stone size, renal pelvis dilatation, and hospitalization time. In 47 % (5/17) of cases, a single session led to complete removal of stones, while the remaining showed either partial improvement or required further procedures. The mean hospitalization time was short (2–3 days), and there were no intraoperative complications. In terms of outcomes, FURSL and FURS were both found to be safe, efficient, and well-tolerated approaches, with minimal morbidity. The procedures provided satisfactory clinical improvements and enhanced the possibility of spontaneous stone passage. The authors conclude that minimally invasive endourological techniques such as flexible ureteroscopy with laser lithotripsy are effective alternatives to open surgery in pediatric urolithiasis, offering faster recovery, lower complication rates, and excellent stone clearance, even in anatomically complex or metabolically predisposed patients.

This article Irene Paraboschi et al. provides an in-depth review of current and emerging surgical strategies for the treatment of pediatric urolithiasis [30]. It highlights how recent advancements in miniaturized technologies and minimally invasive techniques – such as mini-, micro-, and ultra-mini percutaneous nephrolithotomy, as well as vacuum-assisted systems – have significantly improved the safety and effectiveness of urinary stone removal in children. Authors explore cutting-edge innovations like robot-assisted surgery, 3D reconstruction and printing, virtual, augmented, and mixed reality, which enhance surgical planning, accuracy of renal access, and intraoperative visualization. The use of near-infrared fluorescent probes is also discussed as a promising tool for real-time detection of urinary stones. These technological advancements not only reduce complications and hospital stays but also pave the way for more personalized and precise treatment approaches in pediatric urology.

The article Wijnen and Davidoff reviews the growing role of minimally invasive surgery in the treatment of pediatric solid tumors, exploring its benefits, limitations, and oncologic safety [45]. Initially used for biopsy and staging, MIS is now being applied for definitive tumor resection, especially for neuroblastoma and Wilms tumor. Studies show that, in carefully selected cases (e.g., tumors<100 mL and no image-defined risk factors), MIS can achieve high rates of gross total resection (GTR), negative margins, and comparable relapse-free and overall survival to open surgery. They emphasize that while MIS offers advantages – such as reduced blood loss, shorter hospital stays, and quicker return to chemotherapy – there are concerns about limited lymph node sampling, technical complexity, and the risk of tumor spillage or port-site recurrence (though rare in pediatric cases). Proper patient selection, surgeon expertise, and strict adherence to oncologic principles are critical. MIS is most suitable for small, localized tumors that are responsive to neoadjuvant therapy, and its use is expected to increase as techniques improve.

The article Fati F. et al. provides a comprehensive overview of the current role of minimally invasive surgery in the management of pediatric solid tumors [10]. It highlights the growing application of MIS – specifically laparoscopy and thoracoscopy – for both diagnostic biopsies and tumor resections in children. Although MIS has become a standard approach in many pediatric surgical procedures, its incorporation into established pediatric oncology treatment protocols remains limited. The paper reviews the current evidence for MIS use in various tumor types – thoracic neurogenic tumors, thoracic teratomas, pulmonary metastases, adrenal tumors, Wilms tumors, ovarian tumors, and pancreatic lesions – emphasizing indications, contraindications, and outcomes.

S. Chang et al. examines the safety, efficacy, and feasibility of laparoscopic surgery for pediatric neuroblastoma (NB) in cases where no image-defined risk factors (IDRFs) are present [5]. This retrospective study, conducted at Beijing Children's Hospital, included 87 children with localized NB who were treated between December 2016 and January 2021. These patients were divided into two groups: one undergoing open surgery and the other undergoing laparoscopic surgery. The study found that there were no significant differences between the two groups in terms of demographic characteristics, tumor biology, or prognosis. However, the laparoscopic group showed notable advantages, including less intraoperative bleeding and faster recovery, with patients able to resume postoperative feeding earlier than those who underwent open surgery. Furthermore, the postoperative outcomes for both groups were similar, with no recurrence or death observed. The study concluded that laparoscopic surgery is a safe and effective option for treating localized NB in children without IDRFs, offering benefits such as reduced surgical trauma and faster recovery compared to open surgery. In the broader context of oncology, minimally invasive surgery plays an increasingly important role, particularly in pediatric cancers [19, 22, 45]. MIS techniques, such as laparoscopy, provide several advantages over traditional open surgeries, including smaller incisions, reduced blood loss, quicker recovery times, and shorter hospital stays. These benefits are particularly important in pediatric oncology, where preserving organ function and minimizing recovery time can significantly impact long-term health outcomes. Laparoscopic surgery has shown promising results in the treatment of localized tumors, including neuroblastoma, with studies suggesting that it is both safe and effective, as long as there are no contraindicating factors such as IDRFs. The evolution of MIS in oncology continues to expand, as more studies demonstrate its feasibility and advantages in various tumor types, contributing to improved patient outcomes and quality of life.

Minimally invasive surgery has gained significant traction in pediatric surgery due to its clinical benefits, including reduced tissue trauma, quicker recovery times, and improved cosmetic outcomes [3, 9, 20, 23]. However, despite its promising potential, the application of MIS in pediatric patients remains hindered by several challenges, including technical limitations, high costs, and the need for specialized equipment. The current body of literature highlights both the advancements and the barriers faced in the adoption of minimally invasive techniques in pediatric surgery.

One of the most notable technological innovations in MIS is the use of robotic surgery, particularly the da Vinci Surgical System [11, 26, 36]. This technology has shown substantial promise in enhancing precision during complex procedures, such as pyeloplasty and tumor resection. Several studies have demonstrated that robotic surgery allows for improved accuracy and control, reducing the risk of complications and enhancing patient outcomes [16, 43]. However, the high cost of robotic systems, alongside their maintenance, remains a significant economic barrier, limiting their widespread implementation, particularly in low-income regions and smaller healthcare centers [25].

The integration of artificial intelligence (AI) in intraoperative navigation and outcome prediction represents another promising frontier in MIS [12, 24]. AI algorithms, when applied during surgery, could help predict potential complications, guide surgical decision-making, and optimize the planning of operations.

Miniaturization of surgical instruments and the development of flexible endoscopic tools have broadened the scope of MIS for pediatric patients, particularly for neonates and infants [4, 33, 48]. These innovations allow for less invasive procedures with minimal disruption to developing tissues. However, while these advancements hold significant promise, their adoption is contingent on additional clinical trials and further technological improvements to ensure safety and efficacy in pediatric populations.

MIS in paediatric surgery continues to develop as an advanced technique for treating various pathologies in children, including congenital anomalies and oncological diseases. Laparoscopy and thoracoscopy demonstrate significant advantages, such as reduced hospitalisation time, reduced trauma and better cosmetic results. However, for the effective application of these techniques in paediatrics, it is necessary to take into account the peculiarities of paediatric anatomy, the need for specialised equipment and highly qualified specialists. Advances in robotic technology, miniaturised instruments, and artificial intelligence promise further improvements, although issues of cost and accessibility remain relevant. In the future, with additional clinical trials and technological advances, the possibilities of MIS in paediatrics may expand significantly.

Conclusions

1. Minimally invasive surgery showed a significant progress in paediatrics, providing benefits such as reduced trauma, shorter hospital stays and improved cosmetic results.

2. Its use in children presents specific challenges, particularly due to limited anatomical structure and the need for specialised instruments.

3. The use of robotic systems and artificial intelligence promises further improvement of these techniques, although their high cost remains an obstacle to widespread implementation.

4. It is predicted that with the development of technology and additional clinical research, minimally invasive surgery will become more accessible and effective for paediatrics.

5. It is vitally necessary to create standardised protocols and conduct more clinical trials to ensure high-quality results and patient safety for further development.

References

1. Alganabi M, Biouss G, Pierro A. Surgical site infection after open and laparoscopic surgery in children: a systematic review and meta-analysis. Pediatr Surg Int. 2021; 37(8): 973-981. doi: 10.1007/s00383-021-04911-4.
2. Aljuhani A, Alsumaili AA, Alyaseen EM, Daak LI, Esmail A, Alzohari JE. et al. Minimally Invasive Approach Versus Traditional Approach for Treating Congenital Diaphragmatic Hernia: A Systematic Review and Meta-Analysis. Cureus. 2025; 17(1): 77596. doi: 10.7759/cureus.77596.
3. Bindi E, Lisi G, Lauriti G, Cobellis G. Editorial: Minimally invasive pediatric surgery: how to improve and overcome limitations. Front Surg. 2024; 11: 1446901. doi: 10.3389/fsurg.2024.1446901.
4. Boscarelli A, Giglione E, Caputo MR, Guida E, Iaquinto M, Scarpa MG. et al. Robotic-assisted surgery in pediatrics: what is evidence-based?-a literature review. Transl Pediatr. 2023; 12(2): 271-279. doi: 10.21037/tp-22-338.
5. Chang S, Lin Y, Yang S, Yang W, Cheng H, Chang X. et al. Safety and feasibility of laparoscopic resection of abdominal neuroblastoma without image-defined risk factors: a single-center experience. World J Surg Oncol. 2023; 21(1): 113. doi: 10.1186/s12957-023-02997-9.
6. Cullis PS, Fouad D, Goldstein AM, Wong KKY, Boonthai A, Lobos P. et al. Major surgical conditions of childhood and their lifelong implications: comprehensive review. BJS Open. 2024; 8(3):zrae028. doi: 10.1093/bjsopen/zrae028.
7. Davidson EL, Penniston KL, Farhat WA. Advancements in surgical education: exploring animal and simulation models in fetal and neonatal surgery training. Front Pediatr. 2024; 12: 1402596. doi: 10.3389/fped.2024.1402596.
8. Deprest JA, Benachi A, Gratacos E, Nicolaides KH, Berg C, Persico N. et al. Randomized Trial of Fetal Surgery for Moderate Left Diaphragmatic Hernia. N Engl J Med. 2021; 385(2): 119-129. doi: 10.1056/NEJMoa2026983.
9. Dodge-Khatami J, Dodge-Khatami A, Nguyen TD, Rüffer A. Minimal invasive approaches for pediatric & congenital heart surgery: safe, reproducible, more cosmetic than through sternotomy, and here to stay. Transl Pediatr. 2023; 12(9): 1744-1752. doi: 10.21037/tp-23-282.
10. Fati F, Pulvirenti R, Paraboschi I, Martucciello G. Surgical Approaches to Neuroblastoma: Review of the Operative Techniques. Children (Basel). 2021; 8(6): 446. doi: 10.3390/children8060446.
11. Fida Z, Ghutai G, Jamil Z, Dalvi AA, Hassaan M, Khalid K. et al. The Role of Robotics in Cardiac Surgery: Innovations, Outcomes, and Future Prospects. Cureus. 2024; 16(11): 74884. doi: 10.7759/cureus.74884.
12. Gallazzi E, La Maida GA, Cabitza F. Editorial: Clinical Integration of Artificial Intelligence in Spine Surgery: Stepping in a new Frontier. Front Surg. 2023; 10: 1351643. doi: 10.3389/fsurg.2023.1351643.
13. Garzi A, Prestipino M, Calabrò E, Di Crescenzo RM, Rubino MS. Minimally Invasive Treatment of Urolithiasis in Children: Evaluation of the Use of Flexible Ureterorenoscopy and Laser Lithotripsy. Transl Med UniSa. 2020; 22: 46-49.
14. Geleta BE, Bekele BA, Afework M. Spectrum of congenital anomalies of the kidney and urinary tract in a pediatric nephrology clinic in Ethiopia and factors associated with advanced chronic kidney disease: A cross-sectional study. PLOS Glob Public Health. 2024; 4(11) e0003869. doi: 10.1371/journal.pgph.0003869.
15. Gigola F, Amato T, Del Riccio M, Raffaele A, Morabito A, Coletta R. Artificial intelligence in clinical practice: a cross-sectional survey of paediatric surgery residents perspectives. BMJ Health Care Inform. 2025; 32(1): 101456. doi: 10.1136/bmjhci-2025-101456.
16. Handa A, Gaidhane A, Choudhari SG. Role of Robotic-Assisted Surgery in Public Health: Its Advantages and Challenges. Cureus. 2024; 16(6):e62958. doi: 10.7759/cureus.62958.
17. Igwe AO, Talabi AO, Adumah CC, Ogundele IO, Adisa AO, Sowande OA. et al. Mitigating the challenges of laparoscopic paediatric surgery in Ile Ife: The trend so far and lessons learnt. Afr J Paediatr Surg. 2020; 17(3 & 4): 68-73. doi: 10.4103/ajps.AJPS_32_20.
18. König TT, Stefanescu MC, Gianicolo E, Holler AS, Muensterer OJ. Telementoring in Minimally Invasive Esophageal Atresia Repair: Results of a Case-Control Study and Lessons Learned from the TIC-PEA Study (Telemedical Interdisciplinary Care for Patients with Esophageal Atresia). Children (Basel). 2022; 9(3): 387. doi: 10.3390/children9030387.
19. Kremer V, Oliveira Junior WE. The role of Pediatric Surgery in childhood cancer. Rev Assoc Med Bras (1992). 2024; 70 (suppl 1): 2024S110. doi: 10.1590/1806-9282.2024S110.
20. Laguardia S, Piccioni A, Alonso Vera JE, Muqaddas A, Garcés M, Ambreen S. et al. A Comprehensive Review of the Role of the Latest Minimally Invasive Neurosurgery Techniques and Outcomes for Brain and Spinal Surgeries. Cureus. 2025; 17(5): 84682. doi: 10.7759/cureus.84682.
21. Laspro M, Groysman L, Verzella AN, Kimberly LL, Flores RL. The Use of Virtual Reality in Surgical Training: Implications for Education, Patient Safety, and Global Health Equity. Surgeries. 2023; 4(4): 635-646. doi:10.3390/surgeries4040061.
22. Łuczak J, Bagłaj M, Dryjański P, Kalcowska A, Banaszyk-Pucała N, Boczar M. et al. What Should Be the Topics of a Prospective Study on Ovarian Masses in Children?-Results of a Multicenter Retrospective Study and a Scoping Literature Review. Curr Oncol. 2022; 29(3): 1488-1500. doi: 10.3390/curroncol29030125.
23. Mahmoud MA, Daboos MA, Bayoumi ASS, Helal AA, Almaawi A, Hassab MH. et al. Role of Minimally Invasive Surgery in Management of Penetrating Abdominal Trauma in Children. Eur J Pediatr Surg. 2021; 31(4): 353-361. doi: 10.1055/s-0041-1726411.
24. Mansoor M, Ibrahim AF. The Transformative Role of Artificial Intelligence in Plastic and Reconstructive Surgery: Challenges and Opportunities. Journal of Clinical Medicine. 2025; 14(8): 2698. doi: 10.3390/jcm14082698.
25. Mehta A, Cheng Ng J, Awuah AW, Huang H, Kalmanovich J, Agrawal A. et al. Embracing robotic surgery in low- and middle-income countries: Potential benefits, challenges, and scope in the future. Ann Med Surg (Lond). 2022; 84: 104803. doi: 10.1016/j.amsu.2022.104803.
26. Morrell ALG, Morrell-Junior AC, Morrell AG, Mendes JMF, Tustumi F, DE-Oliveira-E-Silva LG. et al. The history of robotic surgery and its evolution: when illusion becomes reality. Rev Col Bras Cir. 2021; 48: 20202798. doi: 10.1590/0100-6991e-20202798.

27. Nguyen H, Pham DH, Luong TH, Nguyen XH, Nguyen DH, Nguyen AK. Laparoscopic and thoracoscopic whole-stomach esophagectomy with preoperative pyloric balloon dilatation for esophageal cancer: a prospective multicenter case-series outcome. BMC Surg. 2024; 24(1): 312. doi: 10.1186/s12893-024-02605-x.
28. O'Brien LP, Hannan E, Antao B, Peirce C. Paediatric robotic surgery: a narrative review. J Robot Surg. 2023; 17(4): 1171-1179. doi: 10.1007/s11701-023-01523-z.
29. Othman W, Lai ZA, Abril C, Barajas-Gamboa JS, Corcelles R, Kroh M. et al. Tactile Sensing for Minimally Invasive Surgery: Conventional Methods and Potential Emerging Tactile Technologies. Front Robot AI. 2022; 8: 705662. doi: 10.3389/frobt.2021.705662.
30. Paraboschi I, Gnech M, De Marco EA, Minoli DG, Bebi C, Zanetti SP. et al. Pediatric Urolithiasis: Current Surgical Strategies and Future Perspectives. Front Pediatr. 2022; 10: 886425. doi: 10.3389/fped.2022.886425.
31. Pelizzo G, Destro F, Pierucci UM, Costanzo S, Camporesi A, Diotto V. 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 (Basel). 2024; 11(6): 679. doi: 10.3390/children11060679.
32. Picozzi P, Nocco U, Labate C, Gambini I, Puleo G, Silvi F. et al. Advances in Robotic Surgery: A Review of New Surgical Platforms. Electronics. 2024; 13(23): 4675. doi:10.3390/electronics13234675.
33. van der Perk MEM, van der Kooi ALF, Broer SL, Mensink MO, Bos AME, van de Wetering MD. et al. A systematic review on safety and surgical and anesthetic risks of elective abdominal laparoscopic surgery in infants to guide laparoscopic ovarian tissue harvest for fertility preservation for infants facing gonadotoxic treatment. Front Oncol. 2024; 14: 1315747. doi: 10.3389/fonc.2024.1315747.
34. Reddy K, Gharde P, Tayade H, Patil M, Reddy LS, Surya D. Advancements in Robotic Surgery: A Comprehensive Overview of Current Utilizations and Upcoming Frontiers. Cureus. 2023; 15(12): 50415. doi: 10.7759/cureus.50415.
35. Rivero-Moreno Y, Echevarria S, Vidal-Valderrama C, Pianetti L, Cordova-Guilarte J, Navarro-Gonzalez J. et al. Robotic Surgery: A Comprehensive Review of the Literature and Current Trends. Cureus. 2023; 15(7): 42370. doi: 10.7759/cureus.42370.
36. Rojas Burbano JC, Ruiz NI, Rojas Burbano GA, Guacho Inca JS, Arragan Lezama CA, González MS. Robot-Assisted Surgery: Current Applications and Future Trends in General Surgery. Cureus. 2025; 17(4): 82318. doi: 10.7759/cureus.82318.
37. Rombaldi MC, Barreto CG, Rombaldi RL, Costa EC, Holanda F, Cavazzola L. et al. Barriers to diffusion and implementation of pediatric minimally invasive surgery in Brazil. BMC Med Educ. 2024; 24(1): 906. doi: 10.1186/s12909-024-05897-y.
38. Rideout DA, Wulkan M. Thoracoscopic Neonatal Congenital Diaphragmatic Hernia Repair: How We Do It. J Laparoendosc Adv Surg Tech A. 2021; 31(10): 1168-1174. doi: 10.1089/lap.2021.0420.
39. Safizadeh Shabestari SA, Nassir N, Sopariwala S, Karimov I, Tambi R, Zehra B. et al. Overlapping pathogenic de novo CNVs in neurodevelopmental disorders and congenital anomalies impacting constraint genes regulating early development. Hum Genet. 2023; 142(8): 1201-1213. doi: 10.1007/s00439-022-02482-5.
40. Surd A, Muresan R, Ciongradi CI, Sur LM, Usatiuc LO, Snakovszki K. et al. Innovations in Minimally Invasive Management of Esophageal Atresia and Tracheoesophageal Fistula. Gastrointestinal Disorders. 2025; 7(2): 39. doi: 10.3390/gidisord7020039
41. Uzun M, Zrara NS, Wodajo EK, Zahra NM, Wojtara M, Uwishema O. Challenges and Innovations in Minimally Invasive Surgery for Pediatric Patients in Africa: A Comprehensive Review. Health Sci Rep. 2025; 8(2): 70437. doi: 10.1002/hsr2.70437.
42. van Hal ARL, Vlot J, van Rosmalen J, Wijnen RMH, van Gils-Frijters APJM, Gischler SJ. et al. Minimally invasive surgical approach in children treated for oesophageal atresia is associated with attention problems at school age: a prospective cohort study. Eur J Pediatr. 2024; 183(5): 2131-2140. doi: 10.1007/s00431-024-05449-y.
43. Wah JNK. The rise of robotics and AI-assisted surgery in modern healthcare. J Robot Surg. 2025; 19(1): 311. doi: 10.1007/s11701-025-02485-0.
44. Watanabe Y, Yamaguchi T, Tanaka S, Sasaki A, Naitoh T, Matsubara H. et al. Characteristics of Childhood Onset and Post-Puberty Onset Obesity and Weight Regain after Laparoscopic Sleeve Gastrectomy in Japanese Subjects: A Subgroup Analysis of J-SMART. Obes Facts. 2022; 15(4): 498-507. doi: 10.1159/000524941.
45. Wijnen MWH, Davidoff AM. Minimally Invasive Techniques in Pediatric Surgical Oncology. Surg Oncol Clin N Am. 2021; 30(2): 417-430. doi: 10.1016/j.soc.2020.11.008.
46. Xie Z, Feng W, Die X, Hou J, Guo Z, Liu W. et al. Single-incision versus conventional multiport laparoscopic-assisted surgery for Meckels diverticulum in children: a single-center propensity score analysis. BMC Pediatr. 2025; 25(1): 344. doi: 10.1186/s12887-025-05695-5.
47. Yalcin S, Bhatia AM, He Z, Wulkan ML. Short- and Long-Term Outcomes of Thoracoscopic and Open Repair for Esophageal Atresia and Tracheoesophageal Fistula. J Pediatr Surg. 2024; 59(12): 161662. doi: 10.1016/j.jpedsurg.2024.08.002.
48. Zahradníková P, Babala J, Lindák M, Pechanová R, Hnilicová S, Molnár M. et al. Systematic review of the training process of minimally invasive surgery in neonates and infants. Pediatr Surg Int. 2025; 41(1): 195. doi: 10.1007/s00383-025-06095-7.

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