EC GYNAECOLOGY
Narrative Review

Robotic-Assisted Surgery in Pediatric and Adolescent Gynecology: Current Evidence and the Emerging Role of Artificial Intelligence - A Narrative Review

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Abstract

Background and Objective: Minimally invasive surgery (MIS) is the standard of care for most gynecological conditions in pediatric and adolescent populations. While robotic-assisted surgery (RAS) has seen widespread adoption in adult gynecology, its application in pediatric and adolescent gynecology (PAG) remains limited by anatomical constraints, instrument size, and specialized training requirements. Concurrently, artificial intelligence (AI) is transforming robotic platforms through enhanced navigation, tool tracking, and automated skill assessment. This narrative review evaluates the current evidence for RAS in PAG and explores how emerging AI applications could overcome existing limitations and shape the future of the field.

Methods: A comprehensive literature search was conducted across PubMed, Scopus, and ScienceDirect for articles published between 2010 and 2026. Keywords included "robotic surgery", "pediatric gynecology", "adolescent gynecology", "artificial intelligence", and "machine learning". Studies detailing clinical outcomes of RAS in PAG, technical limitations in pediatric patients, and AI integration in robotic surgery were synthesized.

Results: Current evidence demonstrates that RAS is safe and feasible for complex PAG indications, including ovarian-sparing surgery for large adnexal masses, excision of Müllerian remnants, and advanced endometriosis. Reported complication and conversion rates are remarkably low, though data remain limited to retrospective series. The primary technical barriers are the discrepancy between standard 8-mm robotic trocars and the limited pediatric abdominal working space. AI applications particularly convolutional neural networks for real-time tool tracking, automated skill assessment using system kinematics, and predictive modeling for surgical planning offer promising solutions to accelerate the steep learning curve and enhance intraoperative safety in confined anatomical spaces.

Conclusion: RAS represents a safe and enabling technology for complex reconstructive and extirpative procedures in PAG. The integration of AI into robotic platforms has the potential to mitigate current technical limitations, standardize training, and improve objective performance metrics. High-quality prospective studies are urgently needed to define standardized indications and validate AI-driven surgical metrics in the pediatric population.

Keywords: *Robotic-Assisted Surgery; Artificial Intelligence; Pediatric and Adolescent Gynecology; Minimally Invasive Surgery; Machine Learning; Surgical Education*

Introduction

Minimally invasive surgery (MIS) has fundamentally transformed the surgical management of gynecological conditions in children and adolescents. The transition from laparotomy to laparoscopy has yielded well-documented benefits, including reduced postoperative pain, shorter hospital stays, fewer adhesion formations, and superior cosmetic outcomes-factors of paramount importance in the pediatric population [1]. Laparoscopy is now considered the gold standard for managing adnexal torsion, ovarian cysts, and early-stage endometriosis in adolescents [2]. However, conventional laparoscopy is inherently limited by two-dimensional visualization, restricted degrees of instrument freedom, and amplified physiologic tremors, which collectively increase the technical difficulty of complex pelvic reconstructions in the confined pediatric pelvis [3].

Robotic-assisted surgery (RAS) was developed to circumvent these limitations. Platforms such as the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA) provide three-dimensional, high-definition magnification, tremor filtration, and wristed instruments with seven degrees of freedom [4]. While RAS has achieved near-ubiquitous adoption in adult gynecologic oncology and urogynecology [5], its penetration into pediatric and adolescent gynecology (PAG) has been notably slower. This lag is primarily attributed to the high capital costs, the steep learning curve, and the technical challenges of deploying standard robotic instruments in small abdominal cavities [6].

Concurrently, the integration of artificial intelligence (AI) into surgical robotics is initiating a second technological revolution. Machine learning (ML) and deep learning architectures, particularly convolutional neural networks (CNNs), are being leveraged to analyze the vast streams of kinematic and visual data generated by robotic platforms [7]. In adult surgery, AI is already being utilized for real-time anatomical navigation, automated surgical skill assessment, and predictive analytics [8].

This narrative review aims to synthesize the current clinical evidence for RAS in pediatric and adolescent gynecology, analyze the unique technical challenges of operating on smaller patients, and explore the emerging role of AI in optimizing robotic performance and training in the PAG specialty.

Current evidence for robotic surgery in PAG

The application of RAS in children initially gained traction in pediatric urology, particularly for pyeloplasty, before gradually expanding to general pediatric surgery and gynecology [9]. In the PAG population, RAS is typically reserved for complex pathology where precise dissection and suturing are required in deep pelvic spaces.

Adnexal masses and ovarian-sparing surgery

The preservation of ovarian tissue is a central tenet of PAG surgery, given the long-term implications for fertility and endocrine function. A recent retrospective review by Fusi., *et al*. analyzed 29 pediatric patients (median age 13.15 years) undergoing robotic gynecological procedures, the majority of which were ovarian or paratubal cystectomies. The authors reported a median operative time of 103 minutes, zero conversions to open surgery, and only one minor (Clavien-Dindo Grade I) complication [10]. Similarly, Cantagalli., *et al*. highlighted RAS as an enabling technology for ovarian-sparing surgery, noting that the enhanced magnification and precise articulation facilitate the delicate separation of the cyst wall from the ovarian cortex, minimizing thermal or mechanical damage to the residual parenchyma [11].

Müllerian anomalies

Congenital anomalies of the female reproductive tract often present with complex, distorted anatomy that challenges conventional laparoscopic approaches. Kebodeaux., *et al*. described the successful robotic-assisted resection of Müllerian remnants in two adolescents with highly complex surgical histories, including cloacal exstrophy and VACTERL association. The authors concluded that the robotic platform allowed for safe, minimally invasive excision in proximity to vital structures, such as the ureters and an ileal conduit, where standard laparoscopy may have required laparotomy [12]. RAS has also been successfully utilized for the excision of accessory cavitated uterine masses (ACUM) and the creation of neovaginas using sigmoid or small intestinal submucosa grafts [13].

Endometriosis

Endometriosis in adolescents often presents with atypical, clear, or red vesicular lesions that can be difficult to visualize with standard laparoscopic cameras. The 3D high-definition visualization of the robotic platform aids in the identification and complete excision of subtle disease. While data specifically focusing on robotic excision of endometriosis in adolescents are scarce, extrapolations from adult literature suggest that RAS is highly effective for deep infiltrating endometriosis, offering superior ergonomics for the surgeon during prolonged, meticulous dissections [5].

Technical challenges in the pediatric patient

Despite its clinical utility, the application of RAS in children is constrained by the physical dimensions of the patients and the robotic hardware.

Port size and working space

The most significant limitation is the size of the robotic instruments. The standard da Vinci trocars require 8-mm incisions, which are disproportionately large for infants and small children [6]. Esposito., *et al*. in a review of 105 pediatric robotic procedures over seven years, noted that the 8-mm port size effectively limits the application of current robotic platforms to children weighing more than 15 kg [9]. Furthermore, the limited domain of the pediatric insufflated abdomen increases the risk of external robotic arm collisions (clashing) and internal instrument crowding [14].

Docking and positioning

Patient positioning and robotic docking require meticulous planning in PAG. The distance between the trocars must be maximized (typically 8 - 10 cm) to prevent arm collisions, which is challenging in a small pediatric abdomen [14]. While newer platforms like the da Vinci Xi feature boom-mounted arms that simplify docking and allow for multiquadrant access, the setup time remains a consideration. However, Esposito., *et al*. demonstrated a significant learning curve effect, with median docking times decreasing from 45 minutes to 15 minutes as the surgical team gained experience [9].

The emerging role of artificial intelligence in robotic surgery

The robotic console serves as a digital interface between the surgeon and the patient, capturing continuous streams of video and kinematic data (instrument position, velocity, and grip force). This data-rich environment is the ideal substrate for AI and ML applications, which are poised to address several of the limitations currently facing RAS in PAG [7].

Real-time navigation and tool tracking

Deep learning models, particularly CNNs, have demonstrated remarkable accuracy in surgical image processing. Padoy., *et al*. utilized CNN architectures to achieve an 87% sensitivity in tool detection and an 88% accuracy in tool localization during robotic surgery [15]. In the confined pediatric pelvis, where the field of view is narrow and the risk of inadvertent injury to adjacent structures is elevated, AI-driven computer vision can provide real-time augmented reality overlays. These overlays can highlight critical structures (e.g. ureters, blood vessels) by integrating preoperative MRI or intraoperative indocyanine green (ICG) fluorescence directly into the surgeon's console, enhancing safety during complex Müllerian anomaly reconstructions [8].

Automated surgical skill assessment

The traditional apprenticeship model of surgical training relies on subjective evaluation by senior surgeons. AI offers a paradigm shift toward objective, automated skill assessment. By analyzing the kinematic data generated by the robotic arms, ML algorithms can differentiate between novice and expert surgeons based on metrics such as path length, economy of motion, and tissue handling forces [16]. Pedrett., *et al*. in a systematic review of AI in MIS skill assessment, found that AI models demonstrated excellent performance in evaluating technical proficiency, though they noted a need for broader external validation [17]. For PAG fellowships incorporating robotics, AI-driven analytics could provide trainees with immediate, objective feedback, potentially accelerating the steep learning curve associated with RAS.

Predictive analytics and preoperative planning

AI algorithms can analyze large, multi-institutional datasets to identify patterns that predict surgical outcomes and complication risks. In surgical planning, AI-assisted image processing allows for the rapid, automated segmentation of pelvic masses or anatomical anomalies from preoperative imaging [8]. This enables the creation of highly accurate, patient-specific 3D virtual models. Surgeons can use these models to simulate trocar placement and instrument reach before the patient enters the operating room, which is particularly valuable when planning robotic surgery for small children where trocar placement margins are unforgiving.

Future directions

The future of RAS in PAG relies on both hardware miniaturization and software evolution. The development of smaller robotic instruments (e.g. 3-mm or 5-mm articulated effectors) and the expansion of single-port robotic platforms (such as the da Vinci SP) will be critical to extending the benefits of RAS to younger, lower-weight pediatric patients [14].

Simultaneously, the integration of AI will transition robotic platforms from mere mechanical extensions of the surgeon's hands into intelligent surgical assistants. As AI models mature, we anticipate the gradual introduction of supervised autonomous actions, such as automated camera tracking or AI-guided suturing, which could reduce cognitive load and operative times.

Conclusion

Robotic-assisted surgery is a safe, feasible, and highly effective modality for managing complex gynecological conditions in pediatric and adolescent patients, particularly for ovarian-sparing procedures and the reconstruction of Müllerian anomalies. While its widespread adoption in PAG is currently hindered by instrument size limitations and the constraints of the pediatric working space, the rapid integration of artificial intelligence offers transformative solutions. AI-driven enhancements in preoperative planning, real-time anatomical navigation, and objective skill assessment have the potential to mitigate existing technical challenges and standardize robotic training. To fully realize this potential, high-quality, multi-institutional prospective studies are required to define standardized indications for RAS in PAG and to validate AI-derived performance metrics in the pediatric surgical environment.

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Conflict of Interest

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Ethical Approval

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