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Narrative Review

Artificial Intelligence and Digital Health in Pediatric and Adolescent Gynecology: A Narrative Review of Emerging Applications and Future Directions

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Abstract

Background: Pediatric and Adolescent Gynecology (PAG) manages a spectrum of complex conditions ranging from congenital Mullerian anomalies to early-onset endometriosis. The diagnostic and surgical challenges inherent to this population often result in delayed care. Artificial Intelligence (AI) and digital health technologies have demonstrated significant potential in adult gynecology, yet their application in PAG remains largely unreviewed.

Objective: This narrative review synthesizes the current literature on AI and machine learning (ML) applications specifically relevant to the pediatric and adolescent gynecological population, identifying clinical gaps and future research directions.

Methods: A comprehensive literature search was conducted to identify studies utilizing AI, ML, or deep learning in the context of PAG conditions, including ovarian torsion, adolescent endometriosis, polycystic ovary syndrome (PCOS), central precocious puberty, and Mullerian duct anomalies.

Results: The literature demonstrates emerging AI applications in three primary domains. First, diagnostic imaging algorithms show high predictive accuracy (87 - 97%) in distinguishing pediatric ovarian torsion from appendicitis. Second, ML models utilizing electronic health record (EHR) data show promise in identifying high-risk cohorts for adolescent endometriosis and central precocious puberty, potentially mitigating the documented 7 - 10 years diagnostic delay. Third, early research suggests deep learning may enhance the classification of complex Mullerian anomalies on magnetic resonance imaging (MRI). However, significant gaps remain in the application of AI to surgical outcomes, postoperative fibrosis prediction, and the mitigation of health disparities in the adolescent population.

Conclusion: AI and digital health platforms hold transformative potential for PAG. Future research must prioritize the development of adolescent-specific algorithms, validated through multi-center trials, to enhance diagnostic precision and personalize surgical care.

Keywords: *Pediatric and Adolescent Gynecology (PAG); Artificial Intelligence (AI); Machine Learning (ML); Electronic Health Record (EHR); Magnetic Resonance Imaging (MRI)*

Introduction

Pediatric and Adolescent Gynecology (PAG) is a rapidly evolving subspecialty that addresses the unique reproductive health needs of patients from infancy through young adulthood. The clinical challenges in PAG are distinct from adult gynecology; patients often present with rare congenital anomalies, atypical manifestations of common diseases, and complex psychosocial needs [1]. Furthermore, diagnostic delays remain a critical issue, particularly for conditions such as endometriosis, where the average delay from symptom onset to diagnosis ranges from 7 to 10 years, severely impacting the adolescent's quality of life and future fertility [2].

In recent years, Artificial Intelligence (AI) and Machine Learning (ML) have catalyzed a paradigm shift in adult obstetrics and gynecology. AI models are now routinely investigated for the interpretation of pelvic ultrasound, the prediction of surgical outcomes, and the risk stratification of gynecological malignancies [3]. However, the translation of these technologies to the pediatric and adolescent population remains fragmented. The anatomical and physiological differences inherent to the developing reproductive tract necessitate the creation of age-specific, rather than adult-extrapolated, algorithms.

This narrative review aims to synthesize the current state of AI and digital health applications in PAG. By examining the integration of ML in the diagnosis of ovarian torsion, adolescent endometriosis, polycystic ovary syndrome (PCOS), precocious puberty, and Mullerian anomalies, this paper identifies current clinical capabilities, existing research gaps, and future directions for AI-assisted surgical and medical management in PAG.

AI in the diagnosis of acute pelvic pain: Pediatric ovarian torsion

Ovarian torsion is a gynecological emergency that presents a significant diagnostic challenge in the pediatric emergency department. The clinical presentation frequently mimics acute appendicitis, and the reliance on sonographic features such as ovarian volume and absent Doppler flow is complicated by the high prevalence of functional cysts and intermittent torsion in adolescents [4].

Recent studies have demonstrated the high utility of ML in differentiating ovarian torsion from other causes of acute pediatric pelvic pain. Turki., *et al*. developed an ML classifier that achieved an average predictive accuracy of 87% to 97% in distinguishing adnexal torsion from appendicitis [5]. Furthermore, Zhao., *et al*. recently constructed and validated a multimodal ML model (OVART-ML) that integrates ultrasound features with inflammatory markers to predict not only torsion but the risk of ischemic necrosis, thereby aiding the surgical decision-making process between conservative detorsion and oophorectomy [6].

The integration of these algorithms into the electronic health record (EHR) as Clinical Decision Support Systems (CDSS) could significantly reduce the time to surgical intervention, a critical factor in pediatric ovarian salvage rates.

Mitigating diagnostic delay: Adolescent endometriosis and PCOS

Adolescent endometriosis

The prolonged diagnostic delay in endometriosis is particularly detrimental during adolescence, a critical window for disease progression. Traditional diagnostic pathways rely heavily on the recognition of cyclic pelvic pain by primary care providers, which is frequently normalized or misattributed [2].

Machine learning offers a novel approach to overcoming this systemic fragmentation. Recent trials, such as the MLEndo study, are investigating the use of ML algorithms applied to primary care EHR data to identify subtle, early clinical patterns such as the frequency of school absences combined with gastrointestinal complaints and dysmenorrhea that predict endometriosis risk [7]. By deploying deep learning architectures to flag high-risk adolescents passively within the EHR, health systems can trigger early referrals to specialized PAG clinics, fundamentally altering the disease trajectory [8].

Polycystic ovary syndrome (PCOS)

The diagnosis of PCOS in adolescents is notoriously complex due to the physiological overlap between normal pubertal development (e.g. acne, irregular menses) and hyperandrogenism [9]. Zad., *et al*. successfully built a predictive model using ML algorithms based on outpatient populations to facilitate the earlier detection of PCOS risk [10]. More recently, ensemble machine learning methods have been applied specifically to adolescent cohorts, utilizing a combination of clinical, hormonal, and demographic data to achieve high diagnostic accuracy without the immediate need for invasive or costly imaging [11].

Congenital and developmental anomalies

Mullerian duct anomalies (MDAs)

Mullerian duct anomalies, including Mayer-Rokitansky-Küster-Hauser (MRKH) syndrome and uterine didelphys, require precise anatomical mapping prior to surgical reconstruction [12]. While 3D ultrasound and MRI are the current gold standards for classification according to the ASRM 2021 guidelines, interpretation remains highly operator-dependent [13].

Ramakrishnan., *et al.* noted that the integration of deep learning algorithms could significantly enhance the accuracy of MRI and 3D-ultrasound interpretation in classifying MDAs [14]. The future application of AI in this domain lies not only in diagnosis but in preoperative surgical planning, where AI-generated 3D models could guide complex neovagina reconstructions and septal resections.

Central precocious puberty

The differentiation between central precocious puberty (CPP) and premature thelarche is critical for determining the necessity of GnRH analog therapy. A recent meta-analysis highlighted the efficacy of ML models integrating clinical, hormonal, and bone age imaging data to predict CPP [15]. Notably, simplified ML models have been developed that utilize easily accessible clinical data prior to the GnRH stimulation test, effectively identifying girls at high risk for CPP and reducing the need for exhaustive endocrine testing in low-risk patients [16].

Future directions and surgical intelligence

While diagnostic AI in PAG is advancing, the application of surgical intelligence remains a profound gap in the literature. Drawing upon recent developments in adult minimally invasive surgery, future PAG research must focus on the following areas:

1. **Predictive modeling for surgical outcomes:** The development of ML algorithms to predict postoperative complications in complex pediatric reconstructive surgery, such as predicting the risk of vaginal fibrosis following MRKH reconstruction based on intraoperative tissue characteristics and patient biometrics.
2. **Digital ERAS platforms:** The adaptation of Enhanced Recovery After Surgery (ERAS) digital platforms specifically for the adolescent population undergoing laparoscopic surgery, utilizing digital health tools to monitor postoperative pain and compliance remotely.
3. **Health equity and NLP:** The utilization of Natural Language Processing (NLP) to analyze clinical notes and identify implicit biases or racial disparities in the diagnostic timelines of adolescent endometriosis and abnormal uterine bleeding, ensuring equitable algorithmic development.

Conclusion

Artificial Intelligence and digital health technologies possess the capability to fundamentally transform Pediatric and Adolescent Gynecology. From highly accurate ML classifiers for ovarian torsion to deep learning algorithms designed to eliminate the diagnostic delay in adolescent endometriosis, the early data is highly promising. However, to fully realize this potential, the field must transition from adult-extrapolated models to rigorously validated, adolescent-specific algorithms. By integrating surgical intelligence and digital

pathways into clinical practice, PAG specialists can offer earlier diagnoses, safer surgical interventions, and highly personalized care to a vulnerable patient population.

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Conflict of Interest

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Ethical Approval

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