



Mini Review

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Artificial Intelligence: How to Improve and Overcome Limitations in Pediatric Surgery?



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Abstract

Background: Artificial intelligence (AI) has been recently shown to improve clinical workflows and outcomes - yet its potential in pediatric surgery remains largely unexplored.

Objective: This work aims to review the role of Artificial intelligence in minimizing poor outcomes and challenges in pediatric surgery.

Results: Recently, the use of AI has gained traction in its ability to predict clinical outcomes using routinely obtained information, such as patient attributes, medical images, and blood test results. However, AI in healthcare systems requires collaboration and training among the partners for successful implementation.

Conclusion, the integration of AI into pediatric surgery heralds a transformative era, offering improved diagnostic accuracy, surgical precision, and enhanced patient outcomes. However, challenges such as ethical considerations and the need for regulatory frameworks underscore the necessity for careful navigation of this evolving landscape.

Keywords: Artificial Intelligence; Poor Outcomes; Machine Learning; Pediatric Surgery; Surgical Navigation

Abbreviations: AI: Artificial Intelligence; NLP: Natural Language Processing; ML: Machine Learning; AR: Augmented Reality; MR: Mixed Reality

Introduction

Artificial intelligence (AI) models designed to mimic human cognitive functions encompass a variety of statistical techniques and algorithms that allow devices to learn from and respond to their environments [1]. Artificial intelligence includes several fields, such as computer vision (which encompasses algorithms and systems for analyzing digital images and videos), natural language processing (NLP; algorithms that can appropriately interpret and generate meaningful human language), robotics, omics, and machine learning (ML) [2]. Nevertheless, the adoption of ML in healthcare is rate-limited by several factors such as data missingness, bias, applicability, explainability (understandability of the rationale behind the model's output), and privacy and ethical concerns [3]. These factors must be adequately addressed in each model before any clinical use. For children undergoing surgery, accurate diagnosis, timely predictions, and treatment

decisions can be significantly bolstered by the integration of AI in clinical workflows [4]. As AI continues to advance, data on the utility of ML, computer vision, and natural language processing accumulate. However, algorithms do not possess uniform designs; models vary in terms of the quality of the data on which they were trained, performance, validation, and interpretability. Thus, evidence remains fragmented, and clinical adoption is limited. For children undergoing surgery, AI is still in its infancy (Figure 1).

Types and Uses of Artificial Intelligence

AI in Medicine

AIM has evolved dramatically over the past 5 decades. Since the advent of ML and DL, applications of AIM have expanded, creating opportunities for personalized medicine rather than algorithm-only medicine. Predictive models can be used for the diagnosis of

diseases, the prediction of therapeutic response, and potentially preventative medicine in the future. AI may improve diagnostic accuracy, improve efficiency in provider workflow and clinical operations, facilitate better disease and therapeutic monitoring,

and improve procedure accuracy and overall patient outcomes. The progressive growth and development of the AI platform in medicine is chronicled below and organized by specific periods of seminal transformation (Figure 2).

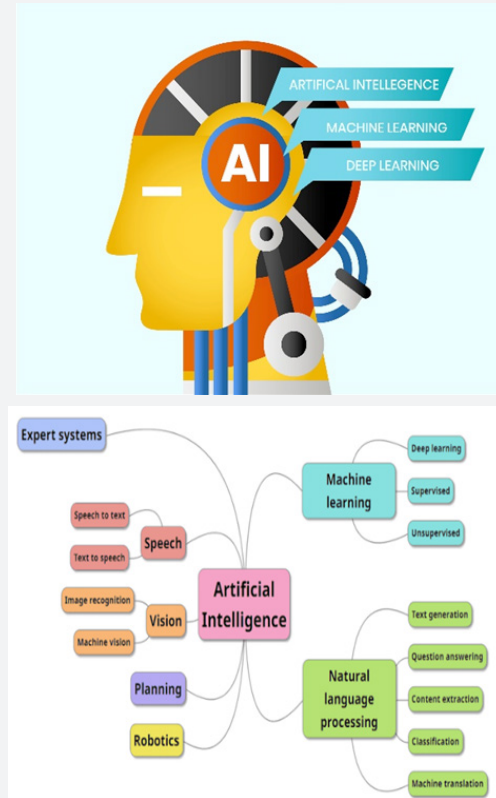


Figure 1: Types and uses of Artificial Intelligence.

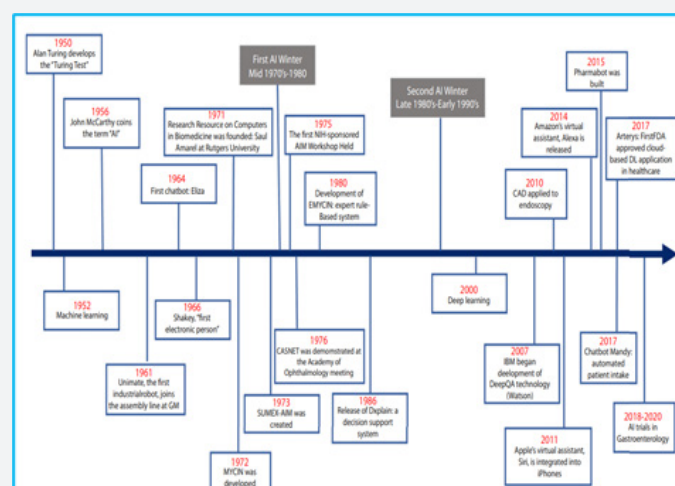


Figure 2: Timeline of the development and use of artificial intelligence in medicine. AI, Artificial intelligence; DL, deep learning; FDA, U.S. Food and Drug Administration; CAD, computer-aided diagnosis.

Artificial Intelligence and Machine Learning in Pediatrics

Machine Learning (ML)

The term “artificial intelligence” was coined by John McCarthy in 1955 [5], defining it as “the science and engineering to make intelligent machines” [6]. Over the years, AI has evolved into a vast field of computer science, leveraging technologies like machine learning to perform tasks that were once thought to require human intelligence, such as problem-solving, pattern recognition, and decision-making [7]. AI has emerged as a transformative ally in pediatrics, where healthcare providers often face intricate tasks demanding advanced human intelligence. The most recent technologies brought forward by AI can provide valuable support by analyzing extensive patient data and offering predictive insights that can be incorporated into early warning systems [3]. Moreover, AI holds the potential to assist medical professionals in making precise diagnoses and suggesting personalized treatment recommendations [8,9]. Beyond this, AI’s capabilities extend into the operating theatre, where it can provide real-time information, robotic assistance, and procedural guidance, further advancing the field of pediatric surgery [10]. Types of AI and their applications to pediatric surgery. There are several types of AI, each with its own unique strengths and applications. We will explore the specific types of AI applications in surgery, the underlying technologies that make them possible, and the tangible benefits they bring to patients and healthcare providers alike.

In surgical contexts, machine learning is most often used in predictive analytics and decision support. ML algorithms have been used to analyze patient data to predict surgical outcomes, complications, and recovery times. By identifying risk factors and optimizing treatment plans, they contribute to better patient care. In the field of surgery, diagnostic and judgment errors stand as the second leading cause of preventable harm among surgical patients, after a technical error [7]. The complexity of surgical decision-making, often conducted under time constraints and amid uncertainty, can inadvertently lead to cognitive shortcuts, introducing biases, errors, and potential harm [3,8,4]. This is where artificial intelligence steps in. ML algorithms can learn intricate, non-linear relationships between input features and outcome labels by training on extensive repositories of electronically stored data [9]. Subsequently, they can generate predictions for new, previously unseen data. The true power of AI emerges when these predictions prove to be accurate, interpretable, and geared toward risk-sensitive decisions (Figure 3). In situations where the optimal choice is unclear and the decision has a significant impact on outcomes, AI predictions can enhance patient care [9]. This enhancement often takes the form of shared decision-making that aligns with patient-centered outcomes, such as short- and long-term quality of life [9].

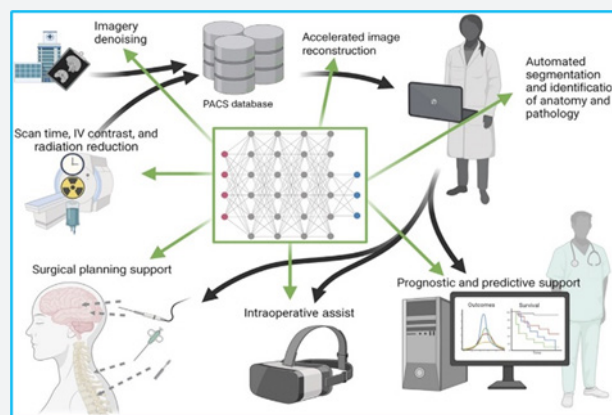


Figure 3: The true power of AI emerges when these predictions prove to be accurate, interpretable, and geared toward risk-sensitive decisions.

Computer Vision

Computer vision is a field of AI that focuses on enabling computers and machines to interpret, understand, and process visual information from the world, much like the human visual system. Computer vision technologies are pivotal in improving the accuracy and efficiency of surgery. Here are some key aspects of AI-powered computer vision in surgery:

Surgical Navigation: Computer vision systems can track surgical instruments in real time, providing precise navigation

assistance to surgeons. This technology aids in maintaining optimal instrument positioning during procedures [11].

Image Segmentation: Image segmentation is a computer vision technique that involves dividing an image into multiple segments or regions based on certain criteria or characteristics. The goal of image segmentation is to partition an image into meaningful and visually coherent segments, where each segment corresponds to a specific object, region, or feature within the image.

Organ Segmentation: AI-driven image segmentation is valuable for identifying and delineating specific organs or structures within medical images. For instance, in lung, liver, or kidney surgeries, AI algorithms can segment and provide 3D reconstructions of these organs, allowing surgeons to navigate complex anatomical structures with greater accuracy [12,13].

Endoscopy and Laparoscopy: AI-based image segmentation is used in endoscopic and laparoscopic surgeries including the pediatric population. It can assist in segmenting and highlighting specific regions of interest within the endoscopic or laparoscopic video feeds, improving visibility and assisting surgeons during minimally invasive procedures.

Intraoperative Navigation: during surgery, AI can assist in segmenting and visualizing relevant structures in real-time. Surgeons can overlay this information onto their field of view using augmented reality (AR) or mixed reality (MR) systems,

enhancing their ability to perform precise surgical maneuvers. In pediatric surgery, the feasibility of AR overlay images on a surgical patient has been tested in six patients undergoing oncological surgery [14].

Natural Language Processing

Natural language processing are algorithms that extract valuable information from unstructured medical text data, such as electronic health records and research articles. They enable efficient data retrieval, analysis, and decision support for surgeons and healthcare providers [15]. Preoperatively, NLP can evaluate surgical indications and reduce the workload of preoperative assessment [16,17]. The system also determined SSI subgroups based on the depth, the wound condition, and the outcome [18]. Furthermore, surgical outcomes can also be automatically extracted from unstructured free text using NLP, which aids labor-intensive manual chart review (Figure 4,5) [19,20].



Figure 4: Surgical Outcomes.



Figure 5: Manual Chart Review.

Beneficial Outcomes Related to AI in Pediatric Surgery

Enhanced Clinical Outcomes

The integration of AI into pediatric surgery can have a direct impact on patient and clinical outcomes, leading to reduced surgical risks. AI technologies, through their predictive analytics and real-time monitoring, contribute to the early identification of potential complications during the perioperative period. In the pediatric surgery population, this is particularly important as there are potentially more compounding factors that can affect a patient's outcome. Through predictive analytics and decision support, AI can play an important role in pattern recognition, health care monitoring and more reliably addressing specific care needs that a patient might have [21,22]. Preoperatively, AI's application in pediatric surgery includes the development of algorithms and clinical prediction tools for diagnosing and managing unique pediatric conditions [23]. Intraoperatively, instruments and technologies continue to develop for pediatric surgery, computer vision and other AI algorithms can enhance pediatric surgeons' ability to perform intricate procedures with improved precision. Postoperatively, the development of wireless sensors and AI-driven remote monitoring devices can also allow healthcare providers to keep a close eye on pediatric surgery patients' progress, providing timely interventions when necessary [24]. The potential for analysis of large amounts of monitored data points and identification of early warning signs by AI could help alert providers of potential complications, prevent readmissions, and reoperation, and save health care dollars. Finally, as

previously discussed, NLP can be used to maintain continuous quality improvement efforts by identifying complications and their details [18].

Reduced Surgical Costs

While the initial investment in AI technology for surgery can be substantial, the long-term benefits could translate into cost reductions realized through fewer complications and optimized resource utilization through quality improvement projects examining the multitude of factors affecting different quality measures. Surgical complication reduction can translate into fewer hospital readmissions and re-interventions, thereby saving healthcare costs. Optimized resource allocation from surgical equipment and operating room time to staff allocation can reduce waste and improve efficiency.

Increased Efficiency

AI-driven tools, such as robotic systems, can improve surgical workflow by automating repetitive tasks, allowing surgeons to focus on critical aspects of the procedure. Machine learning and computer vision have the potential to make pediatric surgeons more efficient in minimally invasive surgeries or through AR/MR technology, allowing them to focus, and potentially assisting with overlapped preoperative imaging, on critical aspects of the operation. As technology allows audiovisual data storage easier and more accessible, AI-assisted annotation, segmentation, and analysis will make it a useful tool in helping surgeons hone their skills and improve future outcomes (Figure 6).

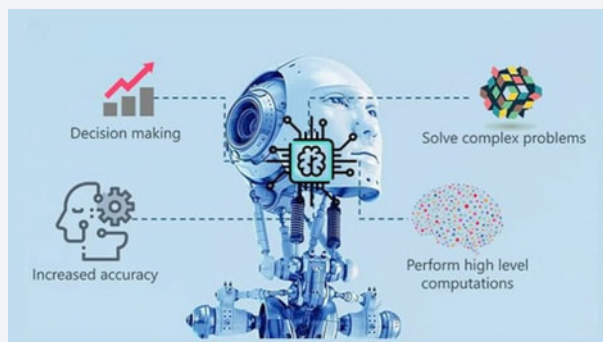


Figure 6: AI-assisted annotation, segmentation, and analysis will make it a useful tool in helping surgeons hone their skills and improve future outcomes.

Challenges and Limitations

While AI offers promising advancements, it's crucial to acknowledge its limitations, especially in the context of pediatric surgery. The strength of AI is its ability to uncover subtle patterns in data. However, for the method to be successful, it requires a large database that is representative of the general population,

and each input is labeled or annotated correctly. Pediatric data sets may have unique biases or limitations, given the smaller patient population and the diversity of developmental stages. In addition, the interpretability of AI algorithms is a significant concern, as pediatric surgeons need to understand the basis of AI-driven recommendations for techniques such as neural networks are based on a "black box" design where how or why such patterns

were discerned by the computer is essentially unknown [25]. Therefore, the accountability of these algorithms, the safety/verifiability of automated analyses, and the implications of these analyses on human-machine interactions can impact the utility of AI in clinical practice [26].

Legal and Ethical Considerations

Liability and Legal Issues

The integration of AI into pediatric surgery introduces complex issues regarding liability and legal responsibility. AI systems in pediatric surgery must undergo rigorous testing and validation to meet regulatory standards and gain approval. This process can be particularly difficult to keep pace with given the rapid advancements in AI technology. As such, the healthcare sector must navigate these legal and regulatory landscapes carefully to effectively integrate AI into pediatric surgery.

Ethical Considerations in Decision Making

AI technologies hold the potential to significantly assist surgeons in decision-making processes, yet their integration into healthcare raises several ethical concerns. Overall, while AI offers substantial benefits in surgical decision-making, addressing these ethical concerns is crucial for its responsible and patient-centered application in healthcare. AI holds tremendous potential to revolutionize pediatric surgery, enhancing both clinical care and surgical education. However, its successful integration requires careful consideration of the unique aspects of pediatric surgery, active involvement of surgeons in AI development, navigation of ethical and regulatory considerations, and a focus on patient and family engagement. With these considerations, AI can significantly contribute to advancing pediatric surgical care, ensuring the highest quality of treatment for young patients (Figure 7).



Figure 7: Challenges of AI in healthcare.

Future Implications for Practice

In the context of the future directions of AI in pediatric surgery, surgical robots like the da Vinci Surgical System, while not inherently AI, incorporate AI algorithms, such as tremor control, to enhance precision in various minimally invasive procedures across specialties. Competing systems in pediatric surgery, including those from Asensus Surgical, also integrate AI into their consoles for improved surgical decision-making [27]. As we envision the future of AI in pediatric surgery, the increasing technical complexity of robotic surgeries necessitates advanced training models for proficiency [28,29]. Additionally, the advancements in telemedicine combined with AI-powered robotic systems can bring much-needed pediatric surgery expertise to remote or underserved areas. Although the use of AI applications has expanded for diagnosing and clinically managing pediatric surgical patients, its intraoperative applications remain limited.

His example illustrates how AI applications like these have the potential to further extend the utilization of intraoperative AI in the future, contributing to enhanced decision-making and surgical outcomes in the field of pediatric surgery [30-41].

Conclusion

In summary, the integration of AI into pediatric surgery heralds a transformative era, offering improved diagnostic accuracy, surgical precision, and enhanced patient outcomes. However, challenges such as ethical considerations and the need for regulatory frameworks underscore the necessity for careful navigation of this evolving landscape.

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