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Review

Unlocking Superior Outcomes: The Power of Artificial Intelligence in Abdominal Hernia Procedures

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Abstract

This review examines the increasing role of artificial intelligence (AI) in abdominal hernia surgery, focusing on its application to inguinal, ventral, and incisional hernias. AI, including machine learning (ML) and deep learning (DL), is being used to enhance surgical planning, provide intraoperative guidance, and improve postoperative outcomes. Generative AI (GAI) and large language models (LLMs) are also contributing to surgical education and research by enabling the creation of tailored surgical strategies and facilitating the analysis of complex medical data. A review of relevant literature from PubMed and Google Scholar indicates that AI has the potential to improve surgical precision, predict complications, and aid in surgical training. However, further research is needed to address limitations in data availability and to fully explore the ethical implications of AI in surgery.

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Keywords: Artificial intelligence, hernia surgery, machine learning, deep learning, surgical outcomes, surgical planning, incisional hernia, ventral hernia.

INTRODUCTION

Artificial intelligence (AI) is the mimicking of human intellect within machines, leading to the development of safer, more accurate, and more effective solutions compared to traditional techniques. Applications of AI include recommendation systems, search engines, self-driving cars, and speech recognition software. According to Zhang and Lu, the term "artificial intelligence" was first introduced in 1956, and the concept has brought numerous benefits to humanity by promoting social progress[1,2].

Many reviews investigate the incorporation of AI in the field of hernia surgery, with a particular focus on the contributions of Machine Learning (ML) and Deep Learning (DL)[3-7]. The umbrella term AI encompasses a number of technological approaches, including ML, Neural Networks (NN), and DL. Traditional ML algorithms rely on organized and labeled information to make predictions, often requiring significant human involvement. Conversely, DL, a specific type of ML, typically uses raw, unlabeled data, such as images and video, to independently recognize patterns and draw sophisticated conclusions. This capability is facilitated by the neural networks used in DL, where intermediate layers between the input and output stages capture intricate data relationships[5]. Consequently, the relationship can be understood as hierarchical: AI represents the broadest domain, ML is a specific domain within AI that focuses on learning from data, DL is a subset of ML that employs deep NNs, and NNs themselves provide the structural framework that underpins deep learning (Figure 1).

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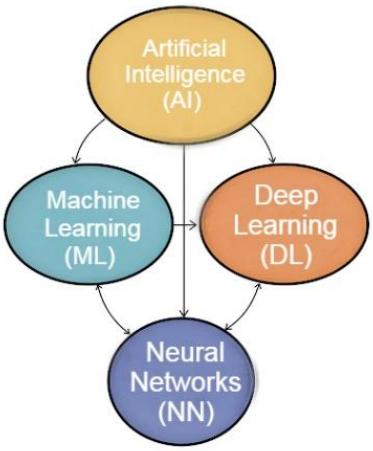

Figure 1. The connection between these concepts follows a top-down structure, progressing from the general to the particular: Artificial Intelligence (AI) represents the broadest field, followed by Machine Learning (ML, a category of AI that focuses on data-driven learning), then Deep Learning (DL, a specialized form of ML that uses deep neural networks), and finally the neural networks (NNs) themselves that form the basis of deep learning capabilities

Another benefit of AI is its ability to ensure greater productivity by facilitating the rapid execution of simple and repetitive tasks. Unlike humans, machines do not experience fatigue when performing tasks that would be tedious for humans. In addition, AI helps reduce the number of human errors[3].

Artificial intelligence is a revolutionary technology with significant impact on various areas within surgery[8], including surgical procedures, research efforts, educational programs, and administrative aspects. Generative AI (GAI) uses algorithms and neural networks to produce novel content, ranging from visual and written materials to surgical strategies. In the medical field, this technology has the potential to be truly transformative[9], providing inventive approaches to complex healthcare problems. Although still a developing field, the use of GAI is growing rapidly, indicating significant potential for surgeons[4].

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Large Language Models (LLMs) such as GPT-3 and GPT-4 (Generative Pre-trained Transformer, OpenAI), LaMDA (Language Model for Dialogue Applications, Google), PaLM (Pathways Language Model, Google), and BLOOM (BigScience workshop and Hugging Face) represent Generative AI (GAI) solutions that utilize a deep learning framework called the Transformer. The transformer framework is particularly well suited for handling sequential data, making it highly suitable for applications involving natural language processing (NLP)[4].

The primary objective of this research is to evaluate the potential of AI in various types of hernia surgery, with the exception of diaphragmatic and hiatal hernias. The specific hernia types that will be examined in this manuscript are inguinal, ventral, and incisional hernias.

DATA SOURCES AND SEARCH

To identify relevant literature, we conducted searches in PubMed and Google Scholar, and then examined the bibliographies of the retrieved articles to identify additional relevant studies. The keywords and their combinations used in our search strategy were: "artificial intelligence" combined with "abdominal hernia", "procedures", "abdominal wall", "inguinal hernia", "ventral hernia", "incisional hernia", and "hernia surgery". The criteria for including publications in this review were direct relevance to the topic of the study. Specifically, we included studies that focused on preoperative preparation, imaging and techniques used during surgery, and postoperative care and follow-up for abdominal wall reconstruction. Publications were excluded if they were not related to hernia surgery and the use of AI in this surgical context, as well as articles that had not undergone peer review. We also excluded studies that did not involve human subjects and duplicate publications. The search was limited to articles published in English. All contributing authors agreed that the articles selected for this review were relevant to the topic.

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TRANSFORMING ABDOMINAL WALL SURGERY WITH GENERATIVE AI: PRACTICE, EDUCATION, AND RESEARCH

Generative AI is not intended to substitute the proficiency and knowledge of experienced surgeons; instead, it aims to augment their capabilities and improve the standard of care delivered to individuals undergoing hernia surgery. Within the domain of surgical practice, generative AI can function as a significant aid to experienced surgeons, providing numerous advantages that can result in better outcomes for patients[4].

A key method through which generative AI supports skilled surgeons is in the area of surgical preparation. Given the inherent complexity of hernia surgery, where each patient case presents distinct challenges, GAI can examine an individual's medical background, imaging results, and other pertinent details to develop tailored surgical strategies. By integrating this information, AI can furnish surgeons with crucial insights, assisting them in making well-informed choices regarding the surgical method, technique, and possible complications. These AI-developed plans serve as a guide that can substantially improve surgical accuracy. Furthermore, the potential of GAI is most evident in facilitating immediate decision-making during the surgical procedure itself[10]. Even highly skilled surgeons can face unforeseen circumstances during operations[4]. In a quality improvement investigation by Elhage et al. [11], the researchers sought to evaluate the capability of image-based deep learning to forecast the difficulty of abdominal wall reconstruction surgeries, particularly the necessity for component separation, as well as to predict lung and wound complications. This study involved comparing a surgical complexity model based on a convolutional neural network with a validation set of Computed Tomography images. To summarize, this study revealed that the convolutional neural network-based DL model demonstrated greater accuracy than the assessments of expert surgeons in predicting the surgical complexity of abdominal wall reconstruction procedures[11]. In another article by Hassan et al. [12], the authors demonstrated the efficacy of machine learning models (MLMs) in predicting hernia

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recurrence, surgical site events, and 30-day readmission rates. The authors concluded by advocating for the incorporation of MLMs into the preoperative assessment of patients undergoing abdominal wall reconstruction.

Generative AI presents a significant prospect for progressing surgical education and research, fundamentally changing the methods by which future surgeons are trained and how medical knowledge is acquired through the examination of extensive data collections[13]. This groundbreaking technology has the capacity to connect conventional medical instruction with the requirements of contemporary healthcare. In the context of surgical training, GAI can be crucial in preparing the upcoming generation of surgeons. AI-powered simulations are especially significant in this aspect[4].

Moreover, AI technology makes a substantial contribution to surgical research by facilitating the analysis of large and intricate medical data sets[10]. Specifically within hernia surgery, AI can glean significant information from electronic medical records, medical imaging, and patient outcome data[4]. In our opinion, to promote the progress of AI in hernia surgery, it is essential to broaden patient databases on a global level. Enhancing the variety and volume of these databases will offer a wider spectrum of data for training AI models, leading to more thorough and precise predictions[5].

AI APPLICATIONS IN PRIMARY ABDOMINAL WALL HERNIA REPAIR

The incorporation of AI into hernia surgery has progressed through its capacity to enhance medical imaging and robotics. AI can improve computer vision by utilizing image acquisition and enhancement applications that support image-guided surgical procedures and computer-assisted diagnosis[14]. The use of robotics in hernia surgery offers possibilities for less invasive procedures while concurrently lowering expenses and the duration of hospital stays[15]. Crucially, it is clear that the integration of AI in medical imaging and robotics has grown over time, notwithstanding the obstacles to its widespread implementation.

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Leveraging AI to Advance Inguinal Hernia Surgery

Inguinal Hernia Surgery is the medical intervention carried out to correct an inguinal hernia. An inguinal hernia develops when tissue, such as a portion of the bowel or fatty tissue, pushes through a weakened region in the abdominal muscles within the groin area, specifically through the inguinal canal. This canal serves as a pathway for the spermatic cord to descend to the testicles in males, and contains the round ligament of the uterus in females. The goal of inguinal hernia surgery is to reposition the protruding tissue and reinforce the abdominal wall by strengthening the weakened area to prevent the hernia from returning. The selection of the surgical approach is influenced by several elements, including the hernia's size and type, the patient's general health condition, and the surgeon's expertise[16].

This surgical procedure is among the most frequently conducted types of repair worldwide. Our search identified many studies, one of which demonstrated the use of AI in inguinal hernia surgery through the successful application of an artificial neural network (ANN) to forecast patient results following a surgical intervention[17]. Another study assessed the efficacy of a convolutional neural network (CNN) in identifying the vas deferens[18]. This research showed that CNN could recognize and label images of the vas deferens during laparoscopic inguinal hernia surgery[18]. Additionally, O'Brien et al. utilized a Network Neural Model to predict the occurrence of long-term skin and soft tissue infections after hernia surgery[19].

The research by Alonso-Silverio et al. showed that AI can be applied to inguinal hernia surgery to create a laparoscopic training platform for providing online education to surgeons. The system's design integrated Python programming, an artificial neural network (ANN), and Raspberry Pi to deliver the training. The study's findings indicated that the system had the potential to boost surgeons' self-assurance and is applicable in settings with limited resources[20]. In a recently published study by Takeuchi et al. [21],

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the main aim was to develop an automated phase recognition system based on deep learning (DL) to identify surgical stages in Transabdominal Preperitoneal (TAPP) procedures and to investigate the link between surgical proficiency and the length of each stage. An AI model was trained to automatically recognize surgical phases from videos, and the study evaluated the correlation between how long each phase lasted and surgical skill levels. A fourfold cross-validation method was used to assess the AI model's performance, achieving accuracy rates exceeding 85%.

In a comparative study by Mito et al. [7], the AI-driven visualization of anatomical reference points during peritoneal dissection in TAPP surgery demonstrated high precision and offered a sufficiently dependable system for surgical assistance. Moreover, in a scoping review by Taha et al. [3], the authors presented a thorough overview of the current aims concerning the incorporation of AI within the domain of hernia surgery. They emphasized the possible uses and advantages of AI in areas like medical imaging and surgical education. However, the authors also noted the limited quantity of published research on this particular subject, suggesting a deficiency in the current body of literature.

Consequently, these points suggest that the field of inguinal hernia surgery has leveraged AI to enhance procedures and ensure the provision of high-quality patient care by anticipating and managing potential complications proactively[3].

Applications of AI in Ventral Hernia Surgery

Ventral hernia surgery is the medical procedure undertaken to correct a ventral hernia. A ventral hernia arises when tissue or an organ, such as a portion of the intestine, protrudes through a weak spot or opening in the abdominal muscles. This often develops at the location of a prior surgical cut but can also occur spontaneously. The purpose of ventral hernia surgery is to return the displaced tissue to its proper place within the abdomen and then strengthen the compromised area of the abdominal wall to

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prevent the hernia from recurring. This strengthening process typically involves stitching the muscle layers together and frequently includes the placement of a synthetic mesh to provide additional support[22].

The incorporation of AI in ventral hernia surgery has been noteworthy, although the application of this concept remains relatively new in this specific area. In their study, López-Cano et al.[23] proposed that utilizing AI methods could enhance patient care by integrating and analyzing a vast number of ventral hernia cases and categorizing them according to severity and priority. The presence of AI in ventral hernia surgery is demonstrated through various studies, among which we highlight the research by Elhage et al., which aimed to apply three deep learning models to forecast the complexity of the procedure and the occurrence of wound infections following a ventral hernia repair[12]. The results of this study indicated that the three image-based models, using computed tomography scans, were effective in predicting surgical complexity and more precise than the assessments made by experienced surgeons[12]. A study by Ayuso et al.[24] focused on developing and comparing deep learning models to predict infrequent but severe postoperative complications after abdominal wall reconstruction, using a database to identify patients with preoperative computed tomography scans. All the aforementioned points suggest that AI holds the promise of improving various aspects of ventral hernia surgery.

SMART INCISIONAL HERNIA SURGERY: THE INTEGRATION OF AI

Incisional hernia surgery is the medical intervention performed to correct an incisional hernia. An incisional hernia is a specific kind of hernia that develops at the location of a prior surgical cut in the abdominal area. It occurs when the abdominal wall muscles become weak at the incision, enabling tissues or organs to protrude[25].

The occurrence of incisional hernias has risen over time, with a primary contributing factor being the increase in obesity rates. However, specialists have shown initiative in

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integrating AI into this field to enhance the standard of care and anticipate complications before they arise, thereby avoiding negative outcomes. In this regard, one study asserted that ML algorithms used in incisional hernia surgery enabled surgeons to make suitable decisions during the operation, ensuring the absence of complications following the hernia repair[26].

Considering all the aforementioned points, it's evident that models designed for the training of surgeons hold significant importance. In this context, we refer to the study by Zipper et al., which developed a model aimed at ensuring competency-based surgeon training. Their approach demonstrated strong reliability and success in improving the technical skills of surgeons[27].

Crucially, Licari et al.[28] employed a Support Vector Machine (SVM) to examine the elements that contribute to the recurrence of incisional hernias in a group of 154 patients. The performance of this technique was outstanding, achieving a sensitivity of 86.25% and an accuracy of 86.67%. Based on the information presented above, it can be inferred that incorporating AI into incisional hernia surgery will lead to favorable results and decrease the occurrence of recurrences.

LIMITATIONS RELATED TO DATA AVAILABILITY

A primary limitation of this study is the limited availability of comprehensive information on the subject. The literature search yielded a relatively small number of relevant documents for inclusion, suggesting that this area remains less explored than its importance might warrant. Another limitation of this review is the exclusive inclusion of articles published in English. This criterion may have contributed to the limited number of sources identified, as relevant information may exist in articles written in other languages.

CONCLUSION

It is clear that there is a significant gap in the literature due to the limited number of articles found suitable for this study. Further research is essential to determine how hernia surgeons and educators can effectively utilize AI. In addition, since the advent of AI, ethical considerations have been a prominent aspect of discussions surrounding this technology. While the potential benefits are clear, there are concerns about liability in the event of complications.

Nevertheless, the significant benefits to surgeons using AI in abdominal wall surgery are evident, particularly in three areas: clinical practice, education, and research. Future researchers investigating this topic should focus on exploring the impact and advancement of AI in hernia surgery. It is recommended that researchers conduct original studies by developing and evaluating AI algorithms to take advantage of their various benefits in inguinal, ventral, and incisional hernia surgery.

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Authors' contributions

Made substantial contributions to conception and design of the study and performed data analysis and interpretation: Golubovic I, Vukadinovic A;

Performed data acquisition, as well as provided administrative, technical, and material support: Golubovic I.

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Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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