Review

ANNALS OF MEDICINE & SURGERY

OPEN

Artificial intelligence in surgical medicine: a brief review

Chen Guo, MD, Yutao He, PhD, Zhitian Shi, PhD, Lin Wang, PhD*

Abstract

The application of artificial intelligence (AI) technology in the medical field, particularly in surgical operations, has evolved from science fiction to a crucial tool. With continuous advancements in computational power and algorithmic technology, AI is reshaping the surgical medicine landscape. From preoperative diagnosis and planning to intraoperative real-time navigation and assistance and postoperative rehabilitation and follow-up management, AI technology has significantly enhanced the precision and safety of surgical procedures. This paper systematically reviews the development and current applications of AI in surgery, focusing on specific case studies of AI in surgical procedures, diagnostic assistance, intraoperative navigation, and postoperative management, highlighting its significant contributions to improving surgical precision and safety. Despite the obvious advantages of AI in improving surgical success, reducing postoperative complications, and accelerating patient recovery, its use in surgery still faces numerous challenges, including its cost-effectiveness, dependency, data privacy and security, clinical integration, and physician training. This review summarizes the current applications of AI in surgical medicine, highlights its benefits and limitations, and discusses the challenges and future directions of integrating AI into surgical practice.

Keywords: artificial intelligence, diagnosis, medical cost, medical dependency, medical education, medical ethics, surgery

Introduction

At first glance, artificial intelligence (AI) might seem mysterious and complex, but it is easier to understand than one might think. As a branch of computer science, AI focuses on machine-driven intelligence or nonhuman intelligence, and its core principle is that human thought processes can be replicated and mechanized[1]. In the complex decision-making processes of surgical operations, surgeons must master a wide range of expertise, including basic sciences, biomedical engineering, education, epidemiology, health services, informatics, law, and public health[2,3]. These extensive and complex assessment requirements often exceed the individual capabilities of surgeons, which is particularly important in this context, as they can simulate and analyze large datasets to help derive optimal treatment strategies, thereby improving surgical success rates and ultimately benefiting patients[4]. This review systematically reviews the main applications of AI in surgical medicine, analyzes its advantages over traditional methods in improving surgical outcomes, and explores the key challenges that need to be addressed for the wider application of AI.

HIGHLIGHTS

- Artificial intelligence (AI) is used in various surgical applications, including preoperative diagnosis, intraoperative navigation, and postoperative management.
- The use of AI in surgical education has been widely explored, particularly in simulation training and personalized learning experiences.
- The advent of AI has precipitated a marked enhancement in the precision of surgical operations when contrasted with conventional surgical methodologies.
- The potential of AI in surgical medicine is evident; however, the article also identifies several challenges, including cost-effectiveness, dependency, data privacy, safety, clinical integration, and physician training.

Methods

A comprehensive search was conducted using the PubMed, Web of Science, Embase, and Cochrane Library databases up to December 2024. Keywords included "artificial intelligence" "surgery" "diagnostic assistance" "dependency" "medical cost" "medical education" and "medical ethics." Intraoperative navigation and postoperative management were also included, and boolean logic operations (AND, OR, NOT) were employed to ensure a comprehensive and precise search. Finally, a systematic review of 56 articles was conducted to represent recent advances in the field. The selection process was conducted in accordance with PRISMA guidelines, and the search terms were independently utilized by two researchers for literature

Department of Hepatobiliary and Pancreatic Surgery, The Second Affiliated Hospital of Kunming Medical University, Kunming, China

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

*Corresponding author. Address: Department of Hepatobiliary and Pancreatic Surgery, The Second Affiliated Hospital of Kunming Medical University, Kunming, 650101, China. Tel.: +86 871 68402722. E-mail: wanglinfey@126.com (L. Wang).

Annals of Medicine & Surgery (2025) 87:2180–2186

Received 13 December 2024; Accepted 17 February 2025

Published online 28 February 2025

http://dx.doi.org/10.1097/MS9.0000000000003115

screening and data extraction. This process encompasses the background of AI research, AI surgical application scenarios, findings, and the main conclusions. Any disagreements were resolved with the involvement of independent third-party authors.

The advancement of AI in healthcare

AI was first proposed by John McCarthy during the Dartmouth Summer Research Project on AI in 1956, however, the earliest pioneer in the field was the renowned Alan Turing, whose groundbreaking work in computational theory and machine intelligence laid the foundation for AI development[5].

The MYCIN system (Stanford University, Palo Alto, CA, USA) was one of the first AI applications in the medical field in 1970. It is based on computer information processing, can diagnose bacterial infections, and recommends antibiotics based on patient data and laboratory results[6]. By the 1980s, the Internist-1 system (IBM, Armonk, NY), with its extensive medical knowledge base, could generate diagnostic hypotheses and recommend further diagnostic steps in a question-and-answer format after receiving initial patient information. This has been widely used in medical diagnosis, further demonstrating the potential of computers to handle complex medical problems[7]. By 2000, with the improvement of computational and data storage capabilities, machine learning and big data analysis had become primary applications of AI in healthcare[8]. Since 2015, AI has achieved full integration and clinical application in the medical field. Deep learning, which utilizes multilayer neural networks for data processing and analysis, has demonstrated significant potential and advantages in medical imaging, disease prediction, and personalized treatment[9,10] (Fig. 1).

At the end of year 2022, the remarkable debut of ChatGPT (OpenAI, Palo Alto, CA) reignited global enthusiasm for AI, surpassing the fervor generated by Google's AlphaGo, defeating the world Go champion Lee Sedol in the year 2016. AI quickly became the focal point, with various industries investing in developing their own AI products; the healthcare sector was no exception. IBM began developing computer technology in the medical field as early as the 1950s, focusing on medical imaging and electronic health record systems. Healthcare solutions have not only helped medical institutions increase efficiency and provide higher quality care, but have also advanced medical technology. In the year 2017, Microsoft established its Healthcare NEXT division, which officially entered the healthcare sector. This year, NVIDIA is dedicated to integrating AI technology with surgical procedures to enhance real-time data analysis during surgery. They plan to apply AI algorithms to surgical decision-making, medical education, and operating room team collaboration to help doctors perform surgeries more accurately and improve their success rates.

Through continuous iterations and advancements, AI has demonstrated several notable advantages over traditional medicine in healthcare. In early disease prediction and diagnosis, AI can identify potential health risks and enable precise screening[11]. It has also facilitated the development of personalized treatment plans, positioning itself as a powerful tool in precision medicine[12]. In addition, AI, when integrated with telemedicine technologies, ensures that patients in remote areas have access to efficient and accurate medical support. As technology continues to evolve, the application prospects of AI in modern healthcare systems have become increasingly expansive.

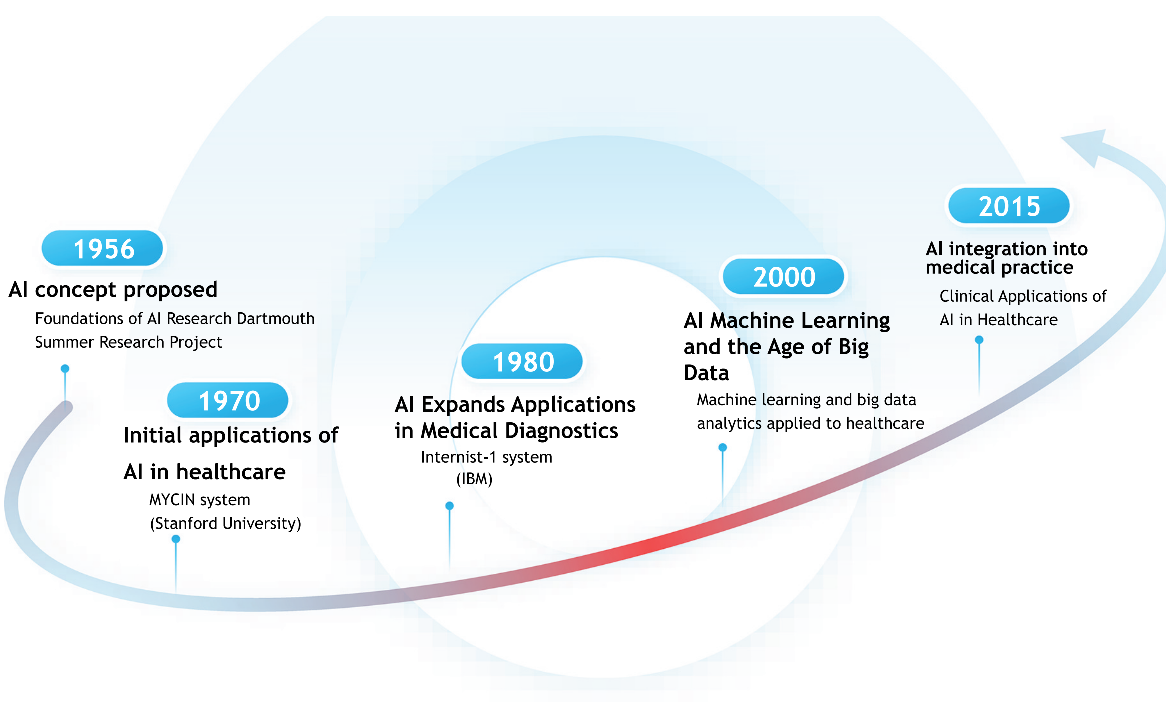

Figure 1. History of AI.

AI in surgery

Radiological imaging techniques play a crucial role in the diagnosis of liver cancer and commonly use magnetic resonance imaging, computed tomography, or contrast-enhanced ultrasonography. The traditional radiological imaging evaluation of tumors primarily relies on qualitative features. These features include tumor density, enhancement patterns, intratumoral cell distribution, regularity of tumor margins, anatomical relationships with surrounding tissues, and their impact on these structures[13]. In many cases, histopathological evaluation is necessary when imaging results are inconclusive. Utilizing AI technology, radiological images, pathological diagnoses, and other types of data can be analyzed for detection and diagnosis. This approach not only aids in assessing disease progression, but also allows for high-precision prognosis prediction, thereby facilitating early diagnosis and determining follow-up schedules for patients[14]. Colorectal cancer (CRC), a gastrointestinal tumor, is the third most common malignancy in both men and women[15]. Numerous studies have shown that the application of AI in CRC screening significantly increases the detection rate of colorectal tumors, making it more effective than conventional endoscopy and radiological examinations[16–18]. This further confirms the exceptional potential and clinical value of AI in early cancer detection. Additionally, ophthalmologists have noted that AI may perform exceptionally well in diagnosing ophthalmic diseases such as macular degeneration, cataracts, diabetic retinopathy, and glaucoma, demonstrating significant screening capabilities[19]. In orthopedic knee and hip replacement surgeries, AI enables precise surgical planning, which not only minimizes errors associated with manual methods, but also shortens surgical duration and reduces the incidence of postoperative complications[20]. Furthermore, AI can predict the risk of dislocation following hip replacement and the need for repair after knee replacement during the postoperative period, thereby providing a critical foundation for early intervention[20]. A study by Lundberg *et al* found that machine learning technology can accurately predict the risk of intraoperative hypoxemia, improving anesthesiologists' prediction accuracy by 15%–30%, and in some cases, nearly doubling the accuracy. This finding is consistent with the existing literature, further demonstrating the importance and potential of AI in medical prediction[21] (Fig. 2). With ongoing technological advancements, AI has been poised to play a pivotal role in a wide range of clinical applications.

The automotive industry is innovating through new intelligent and autonomous technologies, and similar market forces may drive the surgical field towards machine autonomy, further enhancing surgical efficiency and safety[22]. The concept of robot-assisted surgical systems first emerged in the 1970s as a pioneering idea for medical devices that integrate programmable electrical mechanisms to aid surgeons in performing complex surgical procedures[23]. Currently, simple surgical tasks such as millimeter suturing and continuous knotting can be performed autonomously by robots[24]. These advancements demonstrate the potential for surgical automation and lay the groundwork for more complex, autonomous surgeries in the future. The da Vinci Surgical System (Intuitive Surgical, Sunny, CA, USA) is currently the most advanced surgical robot in the world. Its advantages include smaller incisions, reduced intraoperative blood loss, less postoperative pain, and shorter hospital stay and recovery periods[25], One study comparing da Vinci robotic-assisted surgery with traditional laparoscopic surgery in gastric cancer patients confirmed these findings[26]. In another study exploring the use of AI algorithms in robot-assisted gastric cancer surgery, the application of AI algorithms to process preoperative and intraoperative images significantly enhanced image clarity, sensitivity, specificity, and diagnostic accuracy[27]. The da Vinci Surgical Robot, which dramatically improves surgeons' operational precision and surgical visualization capabilities, expands these capabilities even further when combined with AI. This powerful combination has led to the widespread use and popularization of the da Vinci robot in surgical procedures covering a wide range of areas such as general surgery, gynecology,

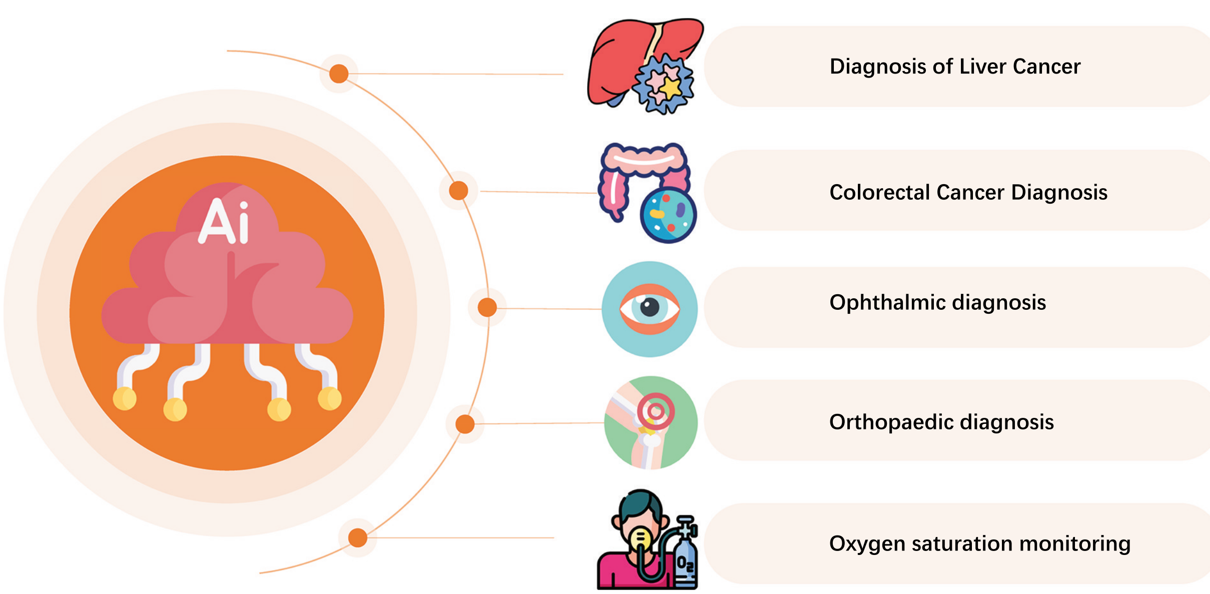

Figure 2. Application areas of AI surgery.

urology, cardiac surgery, orthopedics, and head and neck surgery[28–33].

Augmented reality (AR) and virtual reality (VR) technologies have made significant progress. The original VR technology was created by cinematographers to provide audiences with an immersive audio-visual experience, which was then further advanced by the American artist Myron Krueger, who introduced the concept of AR for the first time by designing a system that allows users to manipulate and interact with virtual objects in real time[34]. With the rapid development of computer technology, VR has entered the practical stage and is used in a number of areas. Launched in 2023, Vision Pro (Apple Inc., Cupertino, California) represents a significant advancement in AR and VR headset technology, with artificial intelligence playing a pivotal role in its operational capabilities. Equipped with high-resolution displays, advanced eye-tracking technology, and real-time data overlay features, Vision Pro enables surgeons to interact with detailed 3D anatomical models and visualize surgical sites with enhanced clarity[35]. The use of the device in surgery is expanding, especially in minimally invasive procedures such as ophthalmology, improving visualization and surgical precision while improving teamwork[36].

Vision Pro holds considerable promise for a wide array of applications in surgical procedures, employing AR for real-time anatomical navigation, preoperative planning, and physiological data visualization[37]. Collectively, these innovative applications underscore the potential of this technology to shape a transformative future in the medical field (Table 1).

Currently, in the field of AI, the large-language ChatGPT model has evolved to version 4o. OpenAI has implemented groundbreaking upgrades, enabling real-time video interaction modes similar to video chatting. If this technology is applied to surgical procedures, by informing the surgical methods in advance and real-time recording of the surgeon's operations into the software, feedback and guidance can be provided. This not only reduces the learning curve for doctors but also significantly increases the success rate of surgeries. Just as a renowned British author, J.K. Rowling depicted in her magical novel "Harry Potter," AI in surgery is becoming a tool as powerful as Harry Potter's wand. In the future, AI may be able to complete simple surgical procedures with only a voice command, marking a significant miracle in the history of human medicine.

Surgical care is equally critical in all stages of a patient's surgery, directly affecting recovery and surgical outcomes. However, the most common issue in surgical care is human error, which includes cognitive mistakes made during care execution, case planning, and problem-solving, these errors occur primarily during surgery, followed by the postoperative and preoperative care stages, human error is a significant cause of adverse events in healthcare services[38]. With the advancement of AI, AI technology can assist nurses in providing precise and personalized evidence-based care by integrating various types of relevant data, thereby enhancing their ability to deliver care in multiple ways and improving nurse-patient relationships[39].

AI for surgeon education

In surgical training, AI enhances attitude training through virtual patient cases and scenarios, enabling trainees to improve their communication and decision-making skills and handle complex ethical issues[40]. It also offers personalized learning experiences by creating realistic surgical simulations, allowing interns to practice in a virtual environment without risking the patients. This method not only improves surgical safety but also reduces the costs associated with surgical training[41]. Correspondingly, understanding intraoperative activities in detail is a common challenge among surgeons in the majority of surgical procedures. Kiyasseh *et al* used surgical AI systems to identify intraoperative activities and examined how surgeons performed these steps and their quality. This can ultimately be used to determine optimal surgical practices and study the relationship between intraoperative factors and postoperative outcomes[42]. Therefore, this technology has a vast development potential. For doctors, it facilitates postoperative review of intraoperative details. Newly appointed clinical interns shorten the learning curve and accelerate accumulation of experience.

One study investigated the perceptions of medical students regarding the application of AI in medical education. The results showed that most students believed that AI would play an important role in healthcare and have a positive impact on medical education. They were willing to use AI in their medical education, but this study also indicated that students generally lack AI-related teaching or training[43]. The potential of AI in the medical field is enormous and its acceptance has been widely recognized. At the same time, this highlights the urgent issue of the lack of AI-related content in current medical education, which often fails to be updated in a timely manner, and the shortage of faculty with AI expertise in medical education, which limits the widespread application of AI in medical education[44].

AI challenges

AI has tremendous potential to enhance clinical practice and patient care, as it not only complements the work of healthcare

Table 1

Key studies on AI applications in surgical medicine.

Author	AI technology	Areas of application	Main findings
Smith *et al*	Machine learning	Intraoperative navigation	Improved precision of tissue removal
Lundberg *et al*	Deep learning	Anesthesia management	Enhanced intraoperative hypoxemia prediction by 15%–30%.
Cheng and Dong	AI algorithms	Da Vinci robotic surgery	Improved image clarity and diagnostic accuracy during surgery.
Mori *et al*	Real-time AI recognition	Colonoscopy	Increased detection rates of colorectal tumors compared to standard methods.
Jayadev and Shetty	Computer vision	Ophthalmic disease diagnosis	Highly effective in screening macular degeneration, cataracts, *etc.*
Kurmis *et al*	Surgical planning AI	Orthopedic surgery	Reduced surgical errors and shortened operation time.
Apple	Vision Pro	Ophthalmic surgery	Improved surgical precision, teamwork

professionals, but also expands the scope of what they can do, providing quantitative skills beyond human capabilities with greater precision and detail[45]. It can also guide treatment by providing the latest clinical guidelines or developments, thereby standardizing treatment and maximizing patient benefits[46].

However, there are several key challenges to the use of AI in healthcare. For example, the situation during surgery often changes dynamically, and AI systems must have the ability to process and respond to constantly updated and complex data in real time, and the current stage of AI technology is still difficult to provide sufficiently rapid and accurate feedback in highly complex surgical environments[47]. In addition, the training of AI systems is highly dependent on a large amount of high-quality and diverse surgical data, particularly in complex and changing surgical scenarios, where instability in the accuracy of the data sources and the quality of the annotation may lead to insufficient model training, thereby triggering bias[48].

It has been widely noted that while computer technology has enhanced efficiency across various industries, its implementation in healthcare has not always led to significant improvements in operational efficiency. When new computer systems are introduced into healthcare settings, medical staff often require extended periods to adapt, resulting in a considerable amount of time spent navigating the system, rather than focusing on patient care. This shift not only detracts from the quality of patient-provider interactions but also highlights the challenges posed by the complexity of these systems. In particular, extensive training requirements and associated time costs represent significant barriers to their effective integration into clinical practice.

In 2017, the National Health Service in the United Kingdom experienced a large-scale "WannaCry" ransomware attack, which caused widespread shutdowns of hospital computer systems and severely disrupted the treatment of tens of thousands of patients[49]. This incident served as a wake-up call for the global healthcare sector, highlighting the vulnerabilities of overreliance on technology. This underscored the difficulty of rapidly restoring functionality in technology-dependent healthcare systems during critical moments, potentially leading to dire consequences.

While AI can assist healthcare professionals in tasks such as medical record documentation, preliminary diagnosis, and health consultations, its integration without clearly defined guidelines and roles can introduce safety risks. For instance, when medical assistants rely on AI without sufficient professional oversight and judgment, it can lead to misdiagnosis or incorrect treatment. Furthermore, excessive dependence on AI by physicians may diminish their ability to handle complex or emergency situations. These issues pose significant threats to patient safety and may give rise to ethical and legal concerns.

However, the emergence of new technologies is often accompanied by high initial costs. In the AI era, the computational power of computer chips plays a critical role in the development of AI technologies, and their prices have surged alongside this wave of innovation. Although hardware prices may gradually decrease as technology matures, high-end chips remain in the premium price range, limiting the widespread adoption of these technologies. Wealthier countries or hospitals can benefit from these advanced technologies, whereas resource-poor regions struggle to access the same level of technological support, exacerbating disparities in healthcare services. Therefore, how AI technology can achieve global accessibility, and how appropriate policies and international collaboration can lower technological barriers are key to addressing this issue.

At the same time, AI in healthcare applications faces the concern that data may be collected, processed, and shared without the knowledge of the user, which triggers privacy leakage. The lack of transparency and interpretability of AI also increases uncertainty in the process of use[50]. When patients are adversely affected by an AI's wrong decisions, the division of responsibility becomes a legal and ethical dilemma[51]. Whether AI can truly follow the medical Hippocratic Oath of "First, do no harm" remains a question that deserves in-depth exploration.

The exciting thing is that the European Union released the Artificial Intelligence Act in 2024, establishing a unified legal framework for AI systems. The bill aims to ensure the safe use of AI within the internal market, protecting public health, privacy, and fundamental rights while also fostering innovation and the application of AI technologies across various industries, particularly in the medical and surgical fields[52]. Additionally, AI systems should be classified based on the risks associated with their application, with high-risk systems required to meet strict compliance standards, such as surgical assistance robots and diagnostic support systems[52]. Ensuring that AI-assisted diagnosis and treatment respects patient privacy during surgery and effectively controls the technology's autonomy strengthens the alignment between regulations and practical use, helping prevent ethical concerns[53].

It is particularly important to emphasize that, despite the continuous advancement of AI technology, we believe it will not replace humans. The role of AI is that of a human-guided tool, and no matter how advanced the technology is, the final decision-making power remains in the hands of human doctors. Human wisdom and experience are paramount: only humans can make comprehensive judgments in complex and dynamic medical environments, handle emergencies, and provide emotional support and ethical care. The human-machine collaboration model drives greater progress in the medical field, not to replace the role of humans.

Conclusion

The application of AI in the field of surgery will open up a new chapter in medical innovation. AI technology, through advanced pattern recognition and machine learning algorithms, can achieve highly personalized medicine and precision surgery, thereby creating customized surgical plans based on patient clinical data. Meanwhile, as AI technology is widely used, its cost-effectiveness, dependency, data security, and ethics are becoming increasingly important. Currently, high costs and complex technologies limit the popularization of AI, particularly in resource-poor areas. Moreover, issues such as data privacy, algorithmic bias, and the division of responsibility pose serious challenges to the safety and ethics of the technology.

In the future, we believe that successful implementation of AI technology will be based on extensive preclinical and clinical practice testing. To ensure their safety and efficacy, AI systems must be extensively validated and optimized, especially in complex and dynamic surgical environments. In addition, specialized training and continuing education for surgeons, as well as qualification for AI applications, are regularly conducted. In this context, close cooperation between medical experts, computer scientists, engineers, and ethicists is coordinated to address the various challenges in the application of this technology and to promote the continuous advancement of AI-assisted surgery. With the continuous maturation and application of these technologies, surgical medicine will enter an unprecedented era of intelligent and humane development.

Ethical approval

Ethical approval was not required for this review.

Consent

Informed consent was not required for this review.

Sources of funding

National Natural Science Foundation of China.

Author's contribution

Conceptualization, data curation, writing – original draft: C.G.; writing – editing: Y.T.H.; writing – editing: Z.T.S.; writing – supervision, writing – reviewing and editing: L.W. All authors reviewed the final version of the manuscript and approved it for submission and publication.

Conflicts of interest disclosure

The authors of this paper have no conflicting interests.

Research registration unique identifying number (UIN)

Not applicable.

Guarantor

Lin Wang.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Data availability statement

Informed consent was not required for this review.

References

[1] Reynoso R. A complete history of artificial intelligence. May 25, 2021.
[2] Zhao J, Forsythe R, Langerman A, *et al*. The value of the surgeon informatician. J Surg Res 2020;252:264–71.
[3] Lyu HG, Doherty GM, Landmana B. Surgical informatics: defining the role of informatics in the current surgical training paradigm. J Surg Educ 2020;77:9–12.
[4] Mirnezami R, Ahmed A. Surgery 3.0, artificial intelligence and the next-generation surgeon. Br J Surg 2018;105:463–65.
[5] Kolanska K, Chabbert-buffet N, Daraï E, *et al*. Artificial intelligence in medicine: a matter of joy or concern? J Gynecol Obstet Hum Reprod 2021;50:101962.
[6] Shorthffe EH. Computer-Based Medical Consultations Mycin. Elsevier; 1976.
[7] Miller RA, Pople HE Jr., Myers JD. Internist-1, an experimental computer-based diagnostic consultant for general internal medicine. N Engl J Med 1982;307:468–76.
[8] Jiang F, Jiang Y, Zhi H, *et al*. Artificial intelligence in healthcare: past, present and future. Stroke Vasc Neurol 2017;2:230–43.
[9] Lecun Y, Bengio Y, Hinton G. Deep learning. Nature. 2015;521:436–44.
[10] Esteva A, Robicquet A, Ramsundar B, *et al*. A guide to deep learning in healthcare. Nat Med 2019;25:24–29.
[11] Mckinney SM, Sieniek M, Godbole V, *et al*. International evaluation of an AI system for breast cancer screening. Nature 2020;577:89–94.
[12] Nishida N. Advancements in artificial intelligence-enhanced imaging diagnostics for the management of liver disease-applications and challenges in personalized care. Bioengineering (Basel) 2024;11:1243.
[13] Bi WL, Hosny A, Schabath MB, *et al*. Artificial intelligence in cancer imaging: clinical challenges and applications. CA Cancer J Clin 2019;69: 127–57.
[14] Calderaro J, Žigutytė L, Truhn D, *et al*. Artificial intelligence in liver cancer—new tools for research and patient management. Nat Rev Gastroenterol Hepatol 2024;21:585–99.
[15] Sung H, Ferlay J, Siegel RL, *et al*. Global Cancer Statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 2021;71:209–49.
[16] Hassan C, Spadaccini M, Iannone A, *et al*. Performance of artificial intelligence in colonoscopy for adenoma and polyp detection: a systematic review and meta-analysis. Gastrointest Endosc 2021;93:77–85.e76.
[17] Mori Y, Kudo SE, Misawa M, *et al*. Real-time use of artificial intelligence in identification of diminutive polyps during colonoscopy: a prospective study. Ann Intern Med 2018;169:357–66.
[18] Ichimasa K, Kudo SE, Mori Y, *et al*. Artificial intelligence may help in predicting the need for additional surgery after endoscopic resection of T1 colorectal cancer. Endoscopy 2018;50:230–40.
[19] Jayadev C, Shetty R. Artificial intelligence in laser refractive surgery—potential and promise!. Indian J Ophthalmol 2020;68:2650–51.
[20] Kurmis AP, Ianunzio JR. Artificial intelligence in orthopedic surgery: evolution, current state and future directions. Arthroplasty 2022;4:9.
[21] Lundberg SM, Nair B, Vavilala MS, *et al*. Explainable machine-learning predictions for the prevention of hypoxaemia during surgery. Nat Biomed Eng 2018;2:749–60.
[22] Loftus TJ, Filiberto AC, Balch J, *et al*. Intelligent, autonomous machines in surgery. J Surg Res 2020;253:92–99.
[23] Klodmann J, Schlenk C, Hellings-kuß A, *et al*. An introduction to robotically assisted surgical systems: current developments and focus areas of research. Curr Robot Rep 2021;2:321–32.
[24] Chow DL, Jackson RC, ÇavuşFoğlu MC, *et al* A novel vision guided knot-tying method for autonomous robotic surgery. Proceedings of the 2014 IEEE International Conference on Automation Science and Engineering (CASE), Piscataway, NJ: Institute of Electrical and Electronics Engineers; 2014, 504-08.
[25] Yu HY, Friedlander DF, Patel S, *et al*. The current status of robotic oncologic surgery. CA Cancer J Clin 2013;63:45–56.
[26] Xie J, Lei Y, Zhang H, *et al*. Comparison of the learning curve of robot-assisted and laparoscopic-assisted gastrectomy. Zhong Nan Da Xue Xue Bao Yi Xue Ban 2023;48:716–24.
[27] Cheng Q, Dong Y. Da Vinci robot-assisted video image processing under artificial intelligence vision processing technology. Comput Math Methods Med 2022;2022:2752444.
[28] Kane WJ, Charles EJ, Mehaffey JH, *et al*. Robotic compared with laparoscopic cholecystectomy: a propensity matched analysis. Surgery 2020;167:432–35.
[29] Capozzi VA, Scarpelli E, Armano G, *et al*. Update of robotic surgery in benign gynecological pathology. Syst Rev Med (Kaunas) 2022;58:552.
[30] Patel VR, Patil NN, Coughlin G, *et al*. Robot-assisted laparoscopic pyeloplasty: a review of minimally invasive treatment options for ureteropelvic junction obstruction. J Robot Surg 2008;1:247–52.
[31] Saber AY, Marappa-Ganeshan R, Mabrouk A; StatPearls. Robotic-Assisted Total Knee Arthroplasty. StatPearls Publishing LLC; 2025.
[32] Niewinski P, Golusiński WJ. Current indications and patient selection for transoral robotic surgery in head and neck cancer—a brief review. Contemp Oncol (Pozn) 2022;26:91–96.

[33] Rosen J, Hannaford B, Satava R. Surgical Robotics: Systems, Applications, and Visions. 2010.
[34] Cipresso P, Giglioli IAC, Raya MA, *et al*. The past, present, and future of virtual and augmented reality research: a network and cluster analysis of the literature. Front Psychol 2018;9:2086.
[35] Kaye AD, Islam RK, Islam KN, *et al*. Apple Vision Pro and its implications in Mohs micrographic surgery: a narrative review. Cureus 2024;16:e71440.
[36] Orione M, Rubegni G, Tartaro R, *et al*. Utilization of Apple Vision Pro in ophthalmic surgery: a pilot study. Eur J Ophthalmol 2025;35:715–21.
[37] Olexa J, Kim KT, Saadon JR, *et al*. Apple Vision Pro augmented reality-assisted minimally invasive surgical treatment of spinal dural arteriovenous fistula. Cureus 2024;16:e63657.
[38] Suliburk JW, Buck QM, Pirko CJ, *et al*. Analysis of human performance deficiencies associated with surgical adverse events. JAMA Netw Open 2019;2:e198067.
[39] Ronquillo CE, Peltonen LM, Pruinelli L, *et al*. Artificial intelligence in nursing: priorities and opportunities from an international invitational think-tank of the nursing and artificial intelligence leadership collaborative. J Adv Nurs 2021;77:3707–17.
[40] Pakkasjärvi N, Luthra T, Anand S. Artificial intelligence in surgical learning. Surgeries. 2023;4:86–97.
[41] Satapathy P, Hermis AH, Rustagi S, *et al*. Artificial intelligence in surgical education and training: opportunities, challenges, and ethical considerations—correspondence. Int J Surg 2023;109:1543–44.
[42] Kiyasseh D, Ma R, Haque TF, *et al*. A vision transformer for decoding surgeon activity from surgical videos. Nat Biomed Eng 2023;7:780–96.
[43] Buabbas AJ, Miskin B, Alnaqi AA, *et al*. Investigating students' perceptions towards artificial intelligence in medical education. Healthcare 2023;11:1298.
[44] Asch DA, Grischkan J, Nicholson S. The cost, price, and debt of medical education. N Engl J Med 2020;383:6–9.
[45] Jones LD, Golan D, Hanna SA, *et al*. Artificial intelligence, machine learning and the evolution of healthcare: a bright future or cause for concern? Bone Joint Res 2018;7:223–25.
[46] Oliveira T, Novais P, Neves J. Development and implementation of clinical guidelines: an artificial intelligence perspective. Artif Intell Rev 2014;42:999–1027.
[47] Hamilton A. The future of artificial intelligence in surgery. Cureus 2024;16:e63699.
[48] Hassan AM, Nelson JA, Coert JH, *et al*. Exploring the potential of artificial intelligence in surgery: insights from a conversation with ChatGPT. Ann Surg Oncol 2023;30:3875–78.
[49] Clarke R, Youngstein T. Cyberattack on Britain's National Health Service—a wake-up call for modern medicine. N Engl J Med 2017; 377:409–11.
[50] Coeckelbergh M. Artificial intelligence: some ethical issues and regulatory challenges. Tech Reg 2019;2019:31–34.
[51] He J, Baxter SL, Xu J, *et al*. The practical implementation of artificial intelligence technologies in medicine. Nat Med 2019;25:30–36.
[52] European Parliament. 2024. Accessed April 10, 2024. https://www.europarl.europa.eu/doceo/document/TA-9-2024-0138_EN.pdf.
[53] European Commission. 2021. Accessed June 14, 2024. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52021PC0206.