The Application of Artificial Intelligence in Medical Surgery

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Abstract

Over the past few centuries, surgical procedures have undergone rapid development, and with the soaring advancements in artificial intelligence (AI) technology, the integration of AI with medical surgery is poised to revolutionize the field. This article explores the synergy of AI and robotics in medical surgery, with a focus on advancements in robot-assisted surgery, AI-driven surgical navigation systems using augmented reality, and the automation of surgical planning and execution. Additionally, the article delves into the complexities of data quality, model interpretability, algorithmic robustness, and the intricacies of patient data privacy and responsibility in AI-assisted surgery. Subsequently, the article examines the technical challenges, ethical implications, and future prospects of AI in surgical procedures. The author also conducted interviews with surgeons to gain insights into their perspectives on the application of AI in surgery from a medical practitioner's standpoint. In conclusion, the article emphasizes the crucial role of collaboration among medical professionals, engineers, and legal experts in addressing these challenges and propelling advancements in the field.

Keywords

Artificial Intelligence, Medical Surgery, Robot-Assisted Surgery, Augmented Reality, Surgical Navigation, Technical difficulties, Ethical Implications.

I. Introduction

Medical surgery, as an integral part of healthcare practice, has undergone a long and illustrious developmental journey. From primitive attempts in the early stages to today's high-tech advancements, the evolution of the field of surgery has not only witnessed a profound understanding of anatomy but also reflected continuous innovation in medical technology. In ancient times, surgical procedures were primarily based on experience and practical knowledge, lacking systematic anatomical understanding. The civilizations of ancient Egypt and Greece laid the groundwork for the development of surgery, but procedures remained perilous and rudimentary. Over centuries, ancient surgeons accumulated rich experiences through practices in both wartime and peacetime.

With the advent of the Renaissance, the rise of anatomy injected new vitality into the development of surgery. Pioneering anatomists like Leonardo da Vinci and Vesalius conducted in-depth studies of the human body, providing a more systematic and scientific foundation for surgical procedures. Discoveries during this period significantly enhanced the precision and safety of surgery. The 20th century witnessed technological leaps in surgery, including the invention of hemostatic instruments, the introduction of aseptic techniques, and advancements in anesthesia. The development of these three major technologies greatly improved the success rate of surgeries and patient survival, transforming surgery into a refined and complex medical specialty.

Artificial Intelligence (AI) involves the programming simulation of human intelligence, mimicking human behaviors such as learning, reasoning, and perception. AI is the intelligence of machines and electronics, with robots acting as active agents in the physical world. The goal of AI technology is to design programs capable of making decisions on their own and executing tasks with higher efficiency and fewer medical errors(Hashimoto et al., 2018). The research fields of AI encompass machine learning, deep learning, natural language processing, computer vision, expert systems, and more. AI applications have permeated various sectors, including healthcare, finance, education, transportation, and beyond. In the medical field, AI is utilized for tasks such

as medical imaging diagnosis, disease prediction, drug development, surgical treatments, providing powerful tools to enhance diagnostic efficiency and accuracy.

In 1985, neurosurgeons performed stereotactic surgery with the assistance of industrial robots, marking the first integration of robotics and surgery(Bargar, 2007). After decades of rapid development, AI has made significant progress in healthcare, and medical robots have gained wide recognition in fields such as cardiac surgery, orthopedics, gastrointestinal surgery, hepatobiliary surgery, and others, showing promising results(Advincula, 2006; Lang et al., 2011). Medical robots can be used to precisely locate lesions during surgery and assist in holding and stabilizing surgical instruments. The combination of AI and medical surgery also enables real-time monitoring of patients' physiological indicators and surgical progress, providing personalized treatment plans and delivering safer, more precise, and individualized medical services to patients. Additionally, it provides powerful tools and support for doctors, reducing the learning curve and propelling the field of surgery into a new era.

II. Intelligent surgical assistance system

Robot-assisted surgery

With the rapid development of artificial intelligence and robotic technology, robot-assisted surgical systems have gradually become a disruptive technology in the field of surgery. Their superiority lies not only in improving the precision of surgical operations but also in providing surgeons with more means of manipulation and richer feedback information. Some of the medical robots have been used into practice (Figure 1).

Figure 1. The series of medical robot

Robot-assisted surgical systems, through advanced mechanical structures and sophisticated sensor technology, translate the manual operations of surgeons into highly precise robotic movements(*Medical Image Computing and Computer-Assisted Intervention – MICCAI 2016*, 2016). This not only makes minimally invasive surgery more feasible, reducing patient surgical trauma, but also lowers the risk of surgical complications. The stability and precision of robots enable surgeons to better handle minute anatomical structures, thereby increasing the success rate of surgeries. The robot arm in the r**π** Tech laboratory of Academician Meng Qinghu, director of the Department of Electronics of Southern University of Science and Technology, has planned the path of knee replacement surgery, and the efficiency and accuracy of the doctor's knee surgery can be well guaranteed by using the robot. (Figure 2).

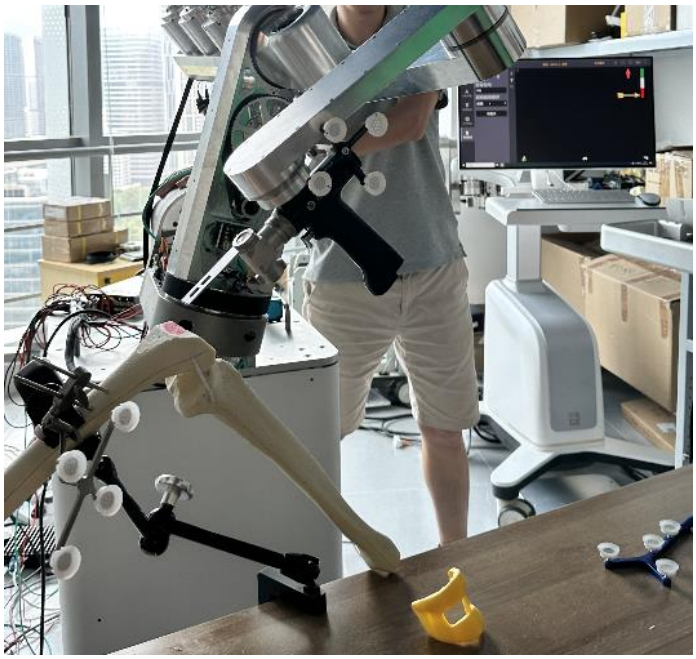

Figure 2. The knee replacement surgery robot arm (from the the rπ Tech laboratory).

However, not all surgeons believe that robot-assisted procedures can have a positive impact on the surgical process. After discussions with several surgeons in the field, it was found that older and more experienced surgeons tend to believe that robotic assistance in surgery may not contribute to the progress of the procedure, some surgeons argue that for a group with high proficiency in surgical skills and related theoretical foundations, learning and practically using a completely new robotic system as surgical assistance may hinder the progress of the surgery and lead to delays in the connection of various surgical components.

In contrast, among younger doctors, the evaluation of the use of medical surgical robots is generally positive. They believe that for a group of doctors with less clinical surgical practice experience, the intervention of medical robots can to some extent compensate for the gap caused by lack of experience between younger and more experienced doctors. After learning and using the robot, there is a noticeable improvement in the speed, success rate, and accuracy of the surgery compared to procedures performed without robotic assistance. In robot-assisted surgery, surgeons manipulate the robotic arms through a console. During this process, the system provides real-time visual feedback and perceptual information, allowing surgeons to have a more intuitive understanding of the surgical area(Goldberg & Falcone, 2003). The high-

resolution cameras and three-dimensional imaging technology of the robotic system offer surgeons a comprehensive and clear surgical scene, enabling them to closely observe minute structures and make more informed decisions. Although there is insufficient research data to conclusively support these perspectives, the varied opinions from different age groups of doctors provide a dialectical view for our exploration of the integration of robots and surgical procedures in this project.

As some doctors have pointed out, robot-assisted surgery demonstrates remarkable performance in handling complex procedures(Gucer et al., 2018; Mäenpää et al., 2015; *Medical Image Computing and Computer-Assisted Intervention – MICCAI 2016*, 2016) such as cardiac surgery and neurosurgery. In fields that require high precision and meticulous operations, robotic systems can serve as valuable assistants to surgeons. The programmability and multiple degrees of freedom of the robotic arms make it easier to perform intricate maneuvers within the constraints of limited surgical spaces. Nowadays, medical surgical robots have gained a certain level of popularity and acceptance(Moustris et al., 2011). After visiting hospitals and attending presentations by relevant professors, we have observed that in some medical institutions, a relatively mature application system for surgical robots has been established（Figure 3）.

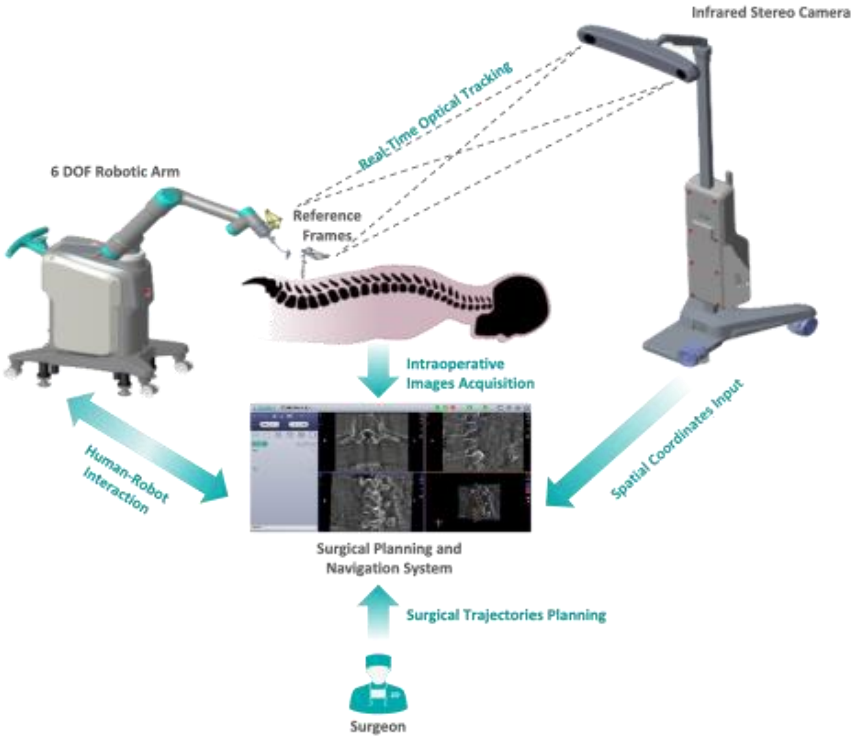

Figure 3. The application of robot in surgery (from Southern University of Science and Technology Hospital)

In spinal surgery, a robot with tracking imaging capabilities provides real-time images to the surgeon. The surgeon formulates relevant medical plans and interacts with the surgical robot to carry out the operation. The interaction between the surgeon and the surgical robot, along with the image delivery function of tracking images, significantly enhances the precision and success rate of the surgery(Goldberg & Falcone, 2003).

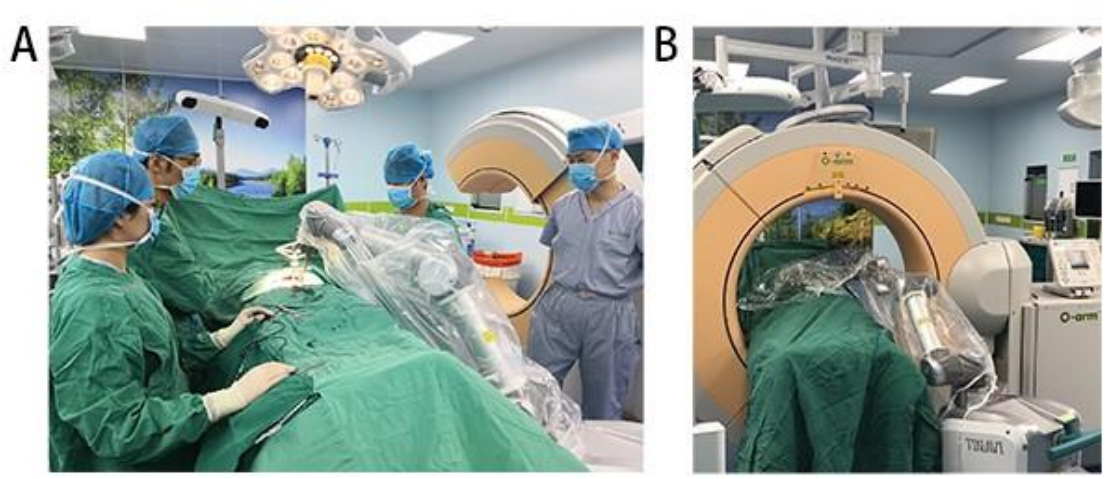

Figure 4. The O-arm assisted Tianji robotic surgery (from Southern University of Science and Technology Hospital)

At the Southern University of Science and Technology Hospital, we encountered a medical surgical robot with an "O"-shaped arm（Figure 4）. Recently, the hospital's orthopedic team successfully completed the first national surgery assisted by the O-shaped arm Tianji robot, showcasing the feasibility and superiority of combining artificial intelligence with surgical procedures. In addition, information from the lectures of relevant professors revealed that surgical robots can effectively reduce the area of some surgical incisions, achieving the goal of minimally invasive procedures. This minimizes patient discomfort, enhances the overall medical and treatment experience for patients. With the assistance of the robot, the implantation of bone screws in the patient's body requires only a minimally invasive procedure on the wrist(Figure 5), significantly reducing the size of the incision compared to traditional

methods. This reduction lowers the risk of postoperative complications and elevates the overall healthcare experience for patients.

Figure 5. The image of a precise surgery assisted by the robot (from Southern University of Science and Technology Hospital)

The latest research in the integration of robotics and surgical medical practices provides a deeper understanding and outlines cutting-edge trends in the field. The current research focus is primarily on the intelligence of robotic systems and the enhancement of surgical procedures through virtual reality. For instance, some studies are dedicated to leveraging deep learning and machine learning technologies to enable robotic systems to better adapt to the anatomical structures of different patients, thereby improving the effectiveness of personalized surgeries.

On the other hand, the integration of virtual reality and augmented reality technologies with robot-assisted surgeries is also a current research hotspot. This fusion provides surgeons with a more immersive surgical experience and offers additional information support for surgical planning and implementation. These research achievements lay a solid foundation for the future development of intelligent-assisted surgical systems, promising more innovations and breakthroughs in the field of surgery.

Artificial Intelligence and Augmented Reality-Driven Surgical Navigation Systems

In the evolution of surgical procedures, the significant transformation brought about by artificial intelligence and augmented reality technologies has revolutionized

the development of surgical navigation systems. Particularly, medical navigation systems based on artificial intelligence and augmented reality have become a hot focus in the recent integration of artificial intelligence and medical surgery.

Traditional surgical procedures face challenges in meeting the demands of modern precision surgery, and the rapid advancement of modern medical imaging technology and medical robotics provides robust support for the emergence of intelligent navigation systems. Among them, surgical navigation systems accurately correlate preoperative or intraoperative medical images with the patient's anatomical structures(*Medical Image Computing and Computer-Assisted Intervention – MICCAI 2016*, 2016).They track the real-time position of surgical instruments within the patient's body and display it in the form of a virtual probe, offering surgeons a clearer and more intuitive surgical field.

To reduce surgical trauma, shorten surgery duration, and enhance surgical quality, computer-assisted surgical navigation systems have gradually found application in clinical practice. Initially, the system reconstructs human anatomy based on preoperative CT or MRI images. Surgeons then determine the actual structure of the surgical area and the required positions using the system. Finally, the system's motion analysis guides surgeons through the surgery, making it faster, more precise, and safer.

With the development of artificial intelligence technology, artificial intelligence is gradually integrated into computer-assisted surgical navigation systems. AI-based computer-assisted surgical navigation systems have become a research hotspot, covering aspects such as image data collection, image processing, surgical planning, spatial localization and system registration, as well as surgical navigation("<Artificial Intelligence and Robotics.pdf>,"). By incorporating extensive patient data and expert knowledge, artificial intelligence enables the system to learn medical knowledge from expert doctors, simulate their thinking and diagnostic reasoning, providing doctors with more reliable diagnostic results and surgical plans.

Mixed reality technology also demonstrates significant potential in the field of cross-regional consultations. By integrating elements of virtual reality (VR) and augmented reality (AR), mixed reality technology provides doctors with an

unprecedented interactive experience, eliminating geographical distance as a limitation for medical collaboration and consultations.

With the support of mixed reality technology, doctors can achieve real-time cross-regional consultations in a virtual medical consultation room. By wearing virtual reality headsets, doctors can collectively observe patients' medical images, case data, and virtual patient anatomical structures. This interactive environment makes doctors feel as if they are in the same location, enabling collaborative discussions, analysis of patient situations, and the provision of more comprehensive and accurate medical opinions. For surgical procedures, mixed reality technology can also provide remote surgical support. Surgeons can remotely guide surgeries through mixed reality platforms, observe the surgical scene, jointly formulate surgical plans, and facilitate collaborative work across different regions (Figure 6).

Figure 6. The Cross-Regional Consultation achieved by MR

Furthermore, mixed reality technology offers new possibilities for medical training and education. Medical students can engage in practical exercises and simulated surgeries in a virtual environment, gaining a more realistic training experience and enhancing their skill levels.

Through mixed reality technology, medical teams can achieve real-time, immersive

cross-regional consultations and collaboration, effectively overcoming geographical barriers and improving the efficiency and quality of healthcare services. The continuous innovation and application of this technology are expected to bring about more breakthroughs and improvements in the field of medicine.

Another application of mixed reality technology is the overlay of real-time medical images. Doctors can use augmented reality (AR) technology to overlay a patient's real-time medical images onto their body, allowing doctors to intuitively observe internal structures on the patient's body surface, thereby enhancing understanding of the patient's condition. In the surgical navigation process, augmented reality (AR) technology and mixed reality (MR) technology are widely applied. AR technology calculates the position and angle of the camera image in real-time and adds the corresponding image to the camera image, providing surgeons with a real-time, precisely matched field of view. This enables doctors to quickly and accurately locate the patient's position and surgical needs, thereby improving the efficiency and success rate of the surgery. Through interviews with surgeons and observing specific operational demonstrations, we found that in practical applications, augmented reality technology can be used for preoperative surgical planning simulations, allowing for a pre-rehearsal of the surgery before it starts, thus enhancing the success rate. It can also magnify deep human anatomical structures during surgery, facilitating surgeons in comprehensive positioning and observation of adjacent and surgical areas (Figure 7).

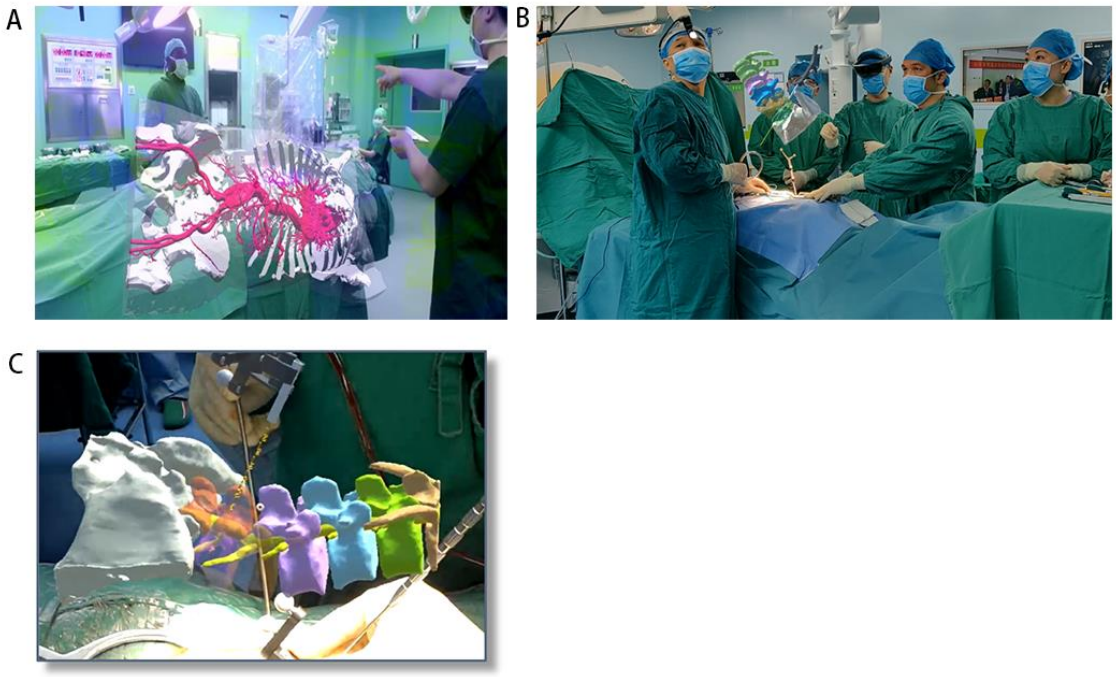

Figure 7. The application of MR in bone surgery (from Southern University of Science and Technology Hospital)

Automated Surgical Planning and Execution

With the rapid advancement of artificial intelligence technology, intelligent surgical planning, a crucial component of surgical procedures, has introduced more sophisticated and personalized planning and execution to significantly enhance the efficiency and quality of surgeries. This innovation not only personalizes surgical paths but also, through the integration of extensive patient data and machine learning algorithms, provides optimal treatment plans for surgeons, achieving the goal of precision medicine.

In intelligent surgical planning, artificial intelligence systems analyze patients' medical images, clinical data, and personalized health information to tailor individualized surgical paths. The advantages of such personalized planning include minimizing surgical risks and enhancing the overall safety of surgeries. Through deep learning and algorithm optimization, the system can offer unique treatment strategies for different cases, providing surgeons with more precise and reliable planning foundations(Ryu et al., 2017).

Moreover, artificial intelligence plays a role in supporting decision-making and optimizing paths in surgical procedures. By integrating vast clinical data and medical knowledge, the system can monitor real-time changes during surgery, offering surgeons immediate feedback and decision support. This real-time analytical capability enables quick adjustments to surgical strategies, improving decision accuracy and maintaining high levels of confidence throughout the entire surgical process.

In real clinical surgeries, some advanced systems integrate robotic technology to achieve automatic control of surgical instruments(Chen & Asch, 2017). This means that robots can perform a series of precise actions during surgery, reducing human errors. Additionally, automated control helps shorten surgical duration, enhance medical efficiency, and prevent resource wastage. The development of automated surgical execution will bring a higher level of precision and efficiency to surgical procedures, providing patients with a safer and more reliable treatment experience.

III. Technical difficulties

In the integration of artificial intelligence (AI) into applications within the medical field, we face a series of complex technological challenges. Firstly, the issue of data quality and annotation poses a significant bottleneck.

Data annotation is crucial for enabling AI to learn from collected data by enriching it with additional knowledge. The most common forms of annotation include classification (e.g., which organs are visible in an image), semantic segmentation (e.g., which pixels belong to which organ in an image), and numerical regression (e.g., the size of an object). The complexity and heterogeneity of medical data introduce uncertainties in its quality, including potential missing, erroneous, or inconsistent data. This not only affects the reliability of the data but also has a direct impact on the training and performance of AI models. Additionally, the annotation process is often time-consuming and requires expert knowledge, making it a high-cost endeavor. The subjectivity of annotations is also a significant challenge, as interpretations of medical images or texts may vary among different healthcare professionals(Bodenstedt et al.,

2020).

Secondly, the issue of model interpretability becomes particularly crucial. Despite the significant achievements of deep learning models in handling medical data, their opacity makes the decision-making process challenging to interpret(Liang et al., 2021). In the medical environment, transparency of AI decisions is paramount, and patients and healthcare professionals need to understand how the model arrives at specific conclusions. Enhancing model interpretability not only increases patients' trust in medical decisions but also helps healthcare professionals better understand and accept AI recommendations.

On the other hand, algorithmic robustness is also a prominent concern. The complexity and uncertainty in the medical field require algorithms to possess strong robustness, maintaining accuracy in the face of different disease variations, clinical practices, and equipment differences. Algorithms need resilience against uncertainties such as noise, variations in image quality, etc., to ensure reliability in real medical scenarios. Therefore, how to maintain the robustness of AI algorithms in complex and dynamic medical environments remains a challenging technical problem that requires in-depth research.

In overcoming these technical challenges, collaborative efforts among medical professionals, computer scientists, data scientists, and legal experts are necessary. Technological innovation, improvement in data standardization, and the establishment and adherence to regulations will provide a solid foundation for the development of medical AI, leading to more accurate, interpretable, and robust applications.

IV. Moral and ethical issues

With the vigorous development of artificial intelligence (AI) technology, its application in the field of medical surgery has raised a series of profound ethical issues. Among them, data privacy and responsibility, along with legal issues, emerge as the most prominent focal points. In medical surgery, AI systems require extensive sensitive medical information from patients, including medical records, surgical histories, and

imaging data. However, the highly sensitive and private nature of this data makes balancing medical technological innovation with the protection of patient privacy a complex and urgent task.

One primary challenge is ensuring the privacy of patient data. Medical information involves extremely private content such as a patient's health condition and medical history, necessitating measures to prevent unauthorized access and potential data breaches. In the context of data sharing, ensuring that data is not misused or accessed by unauthorized third parties is a highly complex issue. Additionally, informed consent from patients is a crucial aspect of protecting data privacy. Patients need to have a clear understanding of how their data will be used for AI system training and application, and they should provide fully informed consent(Collins et al., 2022). Simultaneously, regulations need to ensure that patient privacy is adequately protected during the informed consent process to prevent data misuse. Furthermore, anonymization and de-identification serve as means to address privacy issues, but their implementation is not without challenges. Anonymizing medical data does not absolutely protect against reidentification, requiring a delicate balance between anonymization and data quality.

Another focal issue, responsibility, and legal problems come to the forefront when AI systems provide decision-making or assistance in medical surgery. It is imperative for doctors and medical institutions to clearly define their legal responsibilities when using AI technology. Determining the boundaries of responsibility between doctors and AI systems, as well as tracing responsibility in case of issues, are pressing matters that need resolution(Cobianchi et al., 2022).

In addition to the key issues mentioned above, other ethical concerns in the application of AI in medical surgery include transparency and interpretability, fairness, and bias(Moglia et al., 2021). Addressing these ethical issues requires collaborative efforts from various stakeholders, including medical institutions, technology companies, and regulatory bodies. Clear regulations and ethical guidance, transparent informed consent procedures, and technologically sound data security measures are all necessary means to safeguard patient privacy. Only within a framework of clear legal regulations and ethical standards can the integration of AI with medical surgery better propel

advancements in the medical field while simultaneously protecting patient rights(Yu et al., 2018).

V. Discussion

We had the privilege of engaging in a conversation with Dr. Wang Lin, the Chief of Spinal Surgery at the Southern University of Science and Technology Hospital, who holds the distinction of being the first surgeon to successfully complete the world's inaugural Mixed Reality (MR) guided spinal surgery. Dr. Wang offered insights into the use of surgical robots within hospitals. According to him, for doctors to utilize surgical robots, they must undergo a learning phase to become familiar with operating these advanced technological devices before applying them in actual surgical scenarios. He believes that for young doctors, the support of surgical robots can expedite their learning curve for new surgeries, enhancing operational efficiency. However, for senior doctors with well-established surgical skills, using surgical robots may require additional learning time, and practical application might not be as intuitive. This perspective underscores the importance of physician training and adaptation periods when introducing new technologies to ensure the comprehensive application of surgical robots yields maximum benefits in the healthcare domain. Medical institutions need to formulate flexible training plans to meet the diverse needs of different groups of doctors.

AI has made significant strides in medical surgery, encompassing intelligent surgical planning, robot-assisted surgery, and AI-driven augmented reality surgical navigation systems. These technologies are widely applied in clinical practices, providing convenience for both doctors and patients. However, the development of new technologies is inevitably accompanied by ethical challenges and technical bottlenecks. Collaboration and communication between doctors and engineers are crucial to addressing technical challenges, and new legal regulations need to be enacted to ensure the continuous development of medical technology remains centered around the interests of patients and healthcare quality.

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