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Chapter 6

Robotics and artificial intelligence in surgery: Precision, safety, and innovation

Kiran Kumar Maguluri

IT systems Architect, Cigna Plano, Texas, USA.
kirankumar.maguluri.hcare@gmail.com

Abstract

Robotics and AI are revolutionizing surgery by enhancing precision, safety, and innovation. AI-driven robotic systems assist surgeons in performing complex procedures with increased accuracy, reducing human error, improving recovery times, and ensuring better patient outcomes. These technologies are transforming surgical practices and advancing medical procedures.

Keywords

AI, Innovation, Patient Outcomes, Precision, Robotics, Surgery

6.1. Introduction

In recent years, there has been an increasing interest in the potential effects of robotics and artificial intelligence on surgery—particularly intraoperative surgical procedures. At the heart of this topic is the quest for precision, which is often thought to be reflected in smaller and less invasive robotic-assisted procedures, and safety, claimed to be enhanced by AI systems that amalgamate and interpret diverse patient information to warn of potential death during surgery. Innovation has further centered the spotlight on research into AI systems that can help to plan surgery (Rama, 2022).

Robots and AI have definite and long-term transformative effects on surgery, redefining both the roles of surgeons and gastroenterologists in the modern world of medical practice and the training of our next generation of emerging surgical subgroups. These revolutions are taking place with a blend of technology and localization between industries: surgical technology convergence. The advances in robotics and AI lead to two thought-provoking outcomes: improved console performance as the human-computer interface over networks; and a major shift from being a passive but unanticipated add-on to working on systems and algorithms that the robot can control. Indeed, both our professional development and the positioning of the robot are influenced by increased human sensitivity to robots. AI increases data-driven sensitivity, while robot integration improves the working environment. From diverse and underprivileged environments already have nascent robotic-assisted conferencing and medical colleges. Regulatory and data-rich environments in private healthcare settings are focused on operational tests and health obtained from electronic health data and images for AI systems.

6.1.1. Background and Significance

Minimally invasive surgery (MIS) was not possible until visual technologies could supply an operating field with a view similar in quality to open surgery. Robotic systems for surgery have been developed in response to those nascent technologies and the quest to further enhance visualization, skills translation, and ergonomics for the operating surgeon. Additionally, the inclusion of imaging in the operating room has since evolved the robot from a teaching tool to a unique means of treating pathologies. First, with telestrator control, it progressed to semi-autonomous procedures, such as radiofrequency ablation, and is now widely involved in biopsies and tumor resections. Furthermore, the advent of machine learning and artificial intelligence, increasingly used in hospital systems, is beginning to bring autonomous, individualized therapies within our grasp. Robot and AI-assisted surgery each offer enhancements in the sphere for which visual and surgical control are responsible: precision, safety, and innovation. Put concisely, the surgical robot facilitates the accurately targeted motion of unwieldy but powerful surgical tools, while AI can process vast numbers of inputs or data sets via computer vision and provide decision assistance to the operating surgeon where things become difficult (Danda, 2024).

Robot-assisted surgery has unique features of operation that make humans less required to exist at the patient’s bedside. However, the capability for reducing surgical staff exists on a gradient that moves from what is technologically feasible to what is socially and economically appropriate. We have already seen that the increased efficiency, reliability, and reproducibility of robotic tools have resulted in a radical retrenchment of the whole surgical team, from industry to nurse to surgeon. This is the signature of exponential technologies, and IT, as with all health technologies, has the power to consolidate or expand those in charge. In the case of surgery, the effects of empowering exponential technologies are infinitely more radical. That is the flag that everyone concerned with healthcare should salute, for good or for ill, and we cannot afford to disregard the advances in medical technology. This text will use evidence from various domains of surgery to provide a case to reflect on the place of IT, robotics for surgery, and the arrival and use of big data in surgical environments.

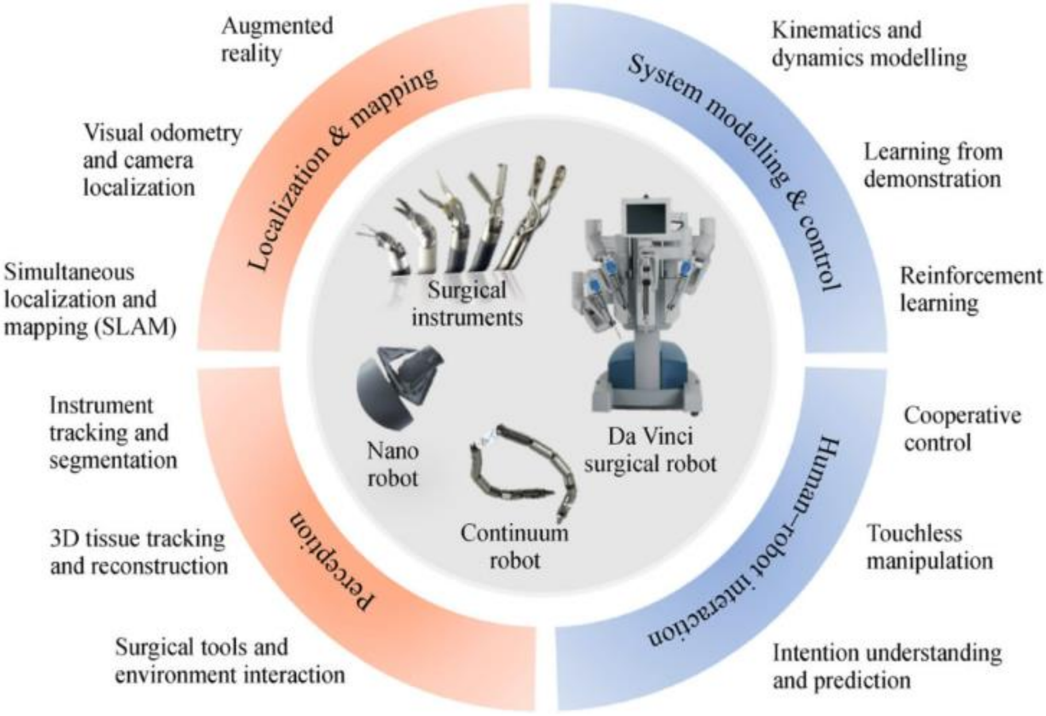

Fig 6 . 1 : Robotics and AI in Surgery.

6.1.2. Purpose of the Paper

The paper aims to provide an opinion on an analytical approach to the surgical aspect of the role of robotics and artificial intelligence. The focus is instead on activities for a single patient's interest that robotics and artificial intelligence can improve, the options that may be introduced, and what is present or emerging, and possibly, the most promising fields of development of this kind of technology in the field of one patient:

surgery. This means considering how much of the robot is handled during the surgical procedure and its non-robotic devices/processes, and the role of artificial intelligence within the robot in analyzing and transforming the data it receives or being able to give its diagnosis.

The purpose of this paper is to illuminate the surge of robotics and artificial intelligence of surgical interest and the ability to change our hands positively. Conversely, this warning, however, tends to immediately bridge the gap to practice with various components of this development since it provides efficiency and precision with the reduction and improvement of safety, but signals clearly and comments at the same time explicitly what the end of these promising applications of robotics and AI to improve humans must be: the starting point from which this development cannot continue freely. Human beings helped through these technologies cannot remain in the dark, and it is neither possible nor correct to ignore this any longer (Syed, 2022). Instead, this aims to enlighten newcomers on this issue and whistleblowers. A review of the continuous studies and the truth up to now on robotics and AI performances in a single patient's purpose, such as surgery, is undertaken. It is almost impossible to respond in a study prepared with today's mood. Even to encounter the excellent efficacy and safety shown by the surgical robot for most of the most representative processes, the elements that later defined the current professional opinion were solicited with an appropriate and innovative factor; this does not inhibit the possibility of acquiring and focusing on analyses that are being expressed. For this detailed purpose, a time-limited look will also be addressed.

6.1.3. Scope and Limitations

SCOPE AND LIMITATIONS: The paper evaluates the effectiveness of robotic and AI applications throughout the surgical continuum, considering the literature published in the last ten years. The review analyzes and discusses the effectiveness of robotic surgery and tele-surgery in vascular, orthopedic, and proctologic cases, and assesses AI and CAD technologies for breast and prostate cancer, gynecological, and abdominal surgery. The three central themes chosen are precision surgery, patient safety risk minimization, and the innovative outcomes that the technologies have realized.

LIMITATIONS: This literature review is time and – perhaps – technology-dependent; it therefore describes the situation present at the time of writing. With time, some of the technological limitations and the underpinning theories that apply to the use of robotic and AI technologies in surgery have been or likely will be addressed. Surgical practice varies within local, regional, national, and international health economies, and therefore the adoption, access, and use of these technologies also vary; this needs to be taken into account when assessing the applicability of the technologies and the outcomes in studies. Finally, when discussing robotics and AI, the ethical and inequity implications require further review. Although the review noted that studies discussed these aspects in their limitations, it is clear that particular implications and developed biases need further consultation across the surgical fields in large and international healthcare organizations.

Equation 1 : Robot Kinematics (Forward Kinematics):

$$T = \prod_{i=1}^{n} T_i$$

T: Transformation matrix representing the end-effector's position and orientation,

T_i: Transformation matrix for the i-th joint,

n: Number of joints.

6.2. Historical Development of Robotics and AI in Surgery

Overall, this paper aims to introduce physicians to the field of surgical robotics and AI and to acknowledge the societal and regulatory questions of the integration of these new technologies into patient care. This section provides evidence for the beginning of a new era of surgery. Probably less widely known, however, is the historical development of robotics and AI in surgical contexts. Revolutionary developments come from many pioneering works. One of the first successful trials of robotics in laparoscopic surgery took place in 1988. A cholecystectomy was assisted by an early prototype of a robotic system. In 1997, a clinical trial for hip replacement surgery was completed and quickly fulfilled all criteria for hospitals. In 2000, many of the robotic companies folded, claiming, among other reasons, to be ahead of the technological age.

Additionally, the area is witnessing efforts on a branch of robotics known as 'soft robotics.' Soft robotics are influenced by the biological world and are not confined to rigid components found in traditional robots (Nampalli, 2021). Fundamental robotics has been theoretically explored for some years. In one such study, activated carbon nanotube technology adapted to natural movements that assemble the acquisitions of multiple neuromorphic sensors. While not currently in routine use in the operating theatre, some research robotic applications have evaluated the predictive nature of artificial intelligence (AI) algorithms. In 2000, the first computer for healthcare policies was created. Several companies have also been involved in AI research. In another pioneering move, a report of a surgical system was submitted for regulatory approval. Today, surgeon robotics are evolving to be better designed, with smaller, smarter parts. AI, in congruence, is rapidly drawing attention to clinical dilemmas. This historical backdrop did nothing if not to shape the future of the new era in operating techniques. If the past is indicative of anything, it’s that surgical specialties have shown a proven ability to tackle both technical and ethical barriers. This, coupled with the motivation and collaboration of academia, engineers, manufacturers, patient users, and regulatory bodies, sets a potentially bright future for robotics and AI in surgery. In summary, history may dictate the limitations of the past and increase our vision for the future.

6.2.1. Early Innovations

When the first teleoperated, supervised robot was proposed, only a few could imagine robot-assisted surgery as it is today. It was hypothesized in the 1980s, and a considerable amount of research was carried out in the following years to lay the groundwork for this surgical revolution. The decade from the late 1980s to the late 1990s can be considered the most promising years for research and innovation in robotics and AI in computational imaging and surgery.

Fig 6 . 2 : Early Innovations

During this era, a few pioneering robotics and AI-assisted systems were proposed, not for clinical use but as a signal of feasibility. For instance, a robotic system for femoral prosthesis implantation was developed in the late 1980s and implanted half of its patients within the trial without any surgeon intervention. This system encouraged the implantation of a new customized knee prosthesis by designing and manufacturing an exact tibia-femoral knee joint by computed tomography, but never really worked as an autonomous robot. These robotic systems were expected to increase precision and reduce the invasiveness of the procedure, thanks to the guidance of the surgeon, keeping their technique in place. In parallel, AI tools were suggested for computer-assisted applications intended to support the surgeon or clinician throughout the surgical workflow, i.e., preoperative planning and intraoperative guidance. Research innovations in the robotics and AI field faced many technical challenges in software and hardware, but also from an ethical and regulatory perspective, and acceptance by the surgical community. Indeed, while some scholars were enthusiastic and confident that robot- and AI assistance would improve the surgical experience and patient-related outcomes, some were skeptical, underestimating the advantages and overestimating the costs as well as the technical and non-technical limitations. Cognitive-based AI in surgery suffered from the shyness of its promises and raised a long-standing debate about its real clinical validation, which has not yet been fully addressed. However, the idea of robotics has gained increasing attention from the surgical community in the following years, and modern robot-assisted surgery is now considered to have many advantages in terms of the surgeon’s comfort. Understanding the historical background of computer-assisted tools is essential to provide perspective on the advancements of the technical capabilities in surgery today (Danda, 2024).

6.2.2. Key Milestones

Milestones in surgery and robotics have been gained by the contribution of manufacturers as well as research institutions. While manufacturers dominate the market and environment today, researchers continue to achieve breakthroughs. The market release of the introduction of surgical robotics and AI products dates back to 2000. This period marks the beginning of the commercial use of surgical robots in minor procedures such as laparoscopic cholecystectomies, gynecologic procedures, and genital surgery. The breakthrough in 2000 accelerated the development of robotic surgical procedures. In particular, in 2002, a joint venture was created to develop an AI-based surgical robotics company. The era of robotics triggered a series of product introductions by various manufacturers.

One of the landmark products is the da Vinci Surgical System, used in 26% of US operating rooms by 2017, and in the United States, more than 500,000 procedures were performed in 2020 using da Vinci. The use of such surgical robots enabled minimally invasive surgery, less-invasive surgery, hand tremor filtering, enhanced 3D visualization, and improved cancer excision with short- and long-term benefits postoperatively. Artificial intelligence has been used in the above platforms in surgical planning phases, enabling objective precision guidance and automated procedures. Regulatory agencies have created a specific body regarding AI. A dedicated product development process, which does not yet exist, is expected for the next few years. Regulatory formulations are having an impact on the safety requirements for the reliability of AI.

6.3. Applications of Robotics and AI in Surgery

Robotics and AI are revolutionizing various aspects of modern medicine. In surgery, these technologies hold tremendous promise. The potential uses can be broadly divided into technical solutions and applications. As technical solutions, AI can potentially streamline the post-processing of imaging and generate actionable data from terabytes of clinical notes and recordings. As applications, these tools can help us solve medical challenges. In this paper, we focus on the latter, discussing the increasing role of robotics and AI in the clinical domain, with an emphasis on specific uses and recent advances.

Robots are becoming increasingly integrated with human surgeons to improve performance and outcomes in multiple surgical specialties. The deployment of robotic technology in select minimally invasive procedures has revolutionized surgical practice for some specialties by showing the potential to reduce recovery times for patients while improving precision. Innovations are also driving increased interest in developing more advanced imaging and visualization systems. Telesurgical and remote surgical applications are potential areas in which advanced robotic systems are used to provide surgical care in areas lacking trained professional surgeons. While the paradigm is not yet used in the developed world, remote medicine or telemedicine is eminently feasible for simple procedures. It thus holds tremendous potential to address medical disparities and improve outcomes. The recent field of AI has begun changing the approach to many research fields within medical imaging and beyond. AI has shown tremendous potential for use as a decision-making aid, predictive analytics tool, and for monitoring patients as well as in prosthetics. Should I use such AI-powered devices, what information can be expected to be reliable, and how do we use the data obtained? In this section, we focus on some key successes where AI and robotic surgical systems are capable of enhancing the outcomes within a given subfield of healthcare.

6.3.1. Minimally Invasive Procedures

Robotic assistance has allowed surgeons to perform a variety of surgical procedures in a minimally invasive manner. Minimally invasive surgery is generally defined as any procedure that requires smaller incisions than those typically associated with open surgery. Two of the most common surgical techniques used within minimally invasive surgery are endoscopy, which uses thin tubes and tools that fit inside the body, and insufflation, in which gas is introduced into the body cavity to inflate the surgeon's operating space. Minimally invasive procedures offer the patient several advantages over traditional open surgery. They have been credited with improving clinical outcomes and resulting in faster recovery rates, shorter hospital stays, smaller scars or sometimes no visible scars, and lower costs of patient recovery for families and society as a whole. Many acceptable outcomes for surgery are industry standards, such as the avoidance of infections and shorter hospital stays. Robotic assistance adds an element above and beyond traditional minimally invasive techniques, improving procedural outcomes such as reduced blood loss, decreased length of catheterization, and protection of surrounding nerves and organs. The additional value of utilizing robotics can also immensely reduce the difficulty of a procedure.

Robotic assistance offering continuous steady manipulation in a tiny incision can be invaluable in providing accuracy and untrammeled dexterity, which is a weakness often associated with laparoscopy. Although evidence supporting the superiority of this method remains under investigation by the surgical community at large, initial clinical trials and the rise of surgeons being trained on these robotic platforms are demonstrative of an upward trend of robotic minimally invasive procedures. Technologies that enable minimally invasive surgery are broken down into three categories: visualization, assistance, and robotics. Robotic technology, in particular, has revolutionized many facets of surgery. The system is thought to be the most commercially successful robotic surgical device. It consists of hand-held manipulators that can be controlled with precision and a range of motion far exceeding those of the human hand. Benefits cited include increased procedural accuracy and faster operations. Both these trends result in decreased fatigue for the surgeon, better outcomes for the patient, and stronger overall process safety. While some surgeons do not anticipate dynamic factors, some believe that the wider adoption of robotic technology in surgical procedures will drive reduced costs as competition in the robotics market continues to increase. Currently, businesses operating in the robotics-in-surgery market have different pricing strategies as they attempt to capture more mature markets, further making the technology more appealing to physicians in the developed world and economically struggling countries. On the other hand, the safety and cost savings associated with the adoption of these novel devices suggest adoption on a wider scale in this country. Robotic technologies within the medical landscape have grown faster than the adoption rate of any other orthopedic or spinal procedure (Kothapalli et al., 2022).

Equation 2 : Force Control for Safety:

$$F = K_p(x_d - x) + K_d(\dot{x}_d - \dot{x})$$

F: Force exerted by the robotic arm,

x_d, x: Desired and actual positions,

$\dot{x}_d$, $\dot{x}$: Desired and actual velocities,

K_p, K_d: Proportional and derivative gains.

6.3.2. Enhanced Imaging and Visualization

One of the most significant repercussions of the synergy between AI/ML and robotics in surgery is the advancements in imaging and visualization that have become available in the operating theater. Such technologies have revolutionized the surgical experience by offering the means to provide an in-depth understanding of clinical-grade segmented 3D reconstructions, helping to reveal the most intricate details of the anatomy of interest. Due to the availability of these images alongside the patient, such detailed information can be exploited for patient-specific preoperative planning and surgical customization. The same data can then be used intraoperatively with the help of both augmented reality and 3D imaging techniques to enable better contextualization and allow for a better understanding of the image data rendered alongside the patient’s anatomy.

Advanced imaging modalities can offer incredible amounts of information about specific types of tissue or the human body in general, from blood flow to bone structure. AI can facilitate content-based image or signal retrieval, variable selection, significantly faster computation in multi-parametric analysis, and display of large multidimensional datasets in new low-dimensional spaces, especially when dealing with high-complexity data such as that generated by multiple modalities or simulations, or in omics data. Practical improvements yielded by AI technologies in the surgical field take advantage of these complex advances in imaging to help surgeons, clinicians, or AI researchers make sense of them, extrapolate information, and, based on the data insights, support surgical planning and guide and assist restoration, helping to improve precision and safety, as well as to limit complications. Because of their ability to synthesize large amounts of data and then propose a more effective and foolproof decision to the surgeon, these tools also have additional potential to improve educational scaffolding. Surgeons in training can take advantage of these tools to aid in better understanding their patients' pathologies and diseases, better comprehend their operative impacts as testified by the image data, and learn some fundamental tips from the AI outputs that they can then apply during surgery. These tools can help reduce learning curves for complex dynamic surgical interventions and pathologies, which can translate into greater institutional support for these technologies. Nonetheless, challenges related to the use of such sophisticated AI and imaging are also starting to emerge, including the need for complex regulatory hurdles and some standardization that is currently lacking in multimodal imaging and medical images reused cross-nationally for an infinite number of purposes.

6.3.3. Telemedicine and Remote Surgery

While robotic surgical systems have found success in assisting surgeons, they have also found great application, particularly in the field of telemedicine. Recently, an area of growing interest and development is remote, image-guided surgical procedures. This includes providing virtual assistance to local surgical teams to carry out procedures on a patient, as well as remote surgery where a surgeon intervenes in an operating room a great distance away using a robotic master console. Drawing on the robotic systems developed for image-guided surgery, a wide range of minimally invasive and remote-assistance surgeries have been completed in locations otherwise unable to perform such procedures. Furthermore, in some cases, these systems have been used to provide real-time virtual support to local surgeons in complex organ-conserving techniques. These procedures can be carried out in rural and resource-poor areas without access to high-quality diagnostic or surgical services. Such surgical procedures depend greatly on three core developments: remote communication between surgical personnel, pre-planning system steps and knowledge, and a robotic system capable of intelligently interacting with tissue (Subhash et al., 2022).

The technological capability for remote surgery procedures has been successfully demonstrated. However, a major obstacle preventing the wide acceptance of robotic-assisted minimal access or remote surgical procedures is the high dependence of these systems on technical infrastructure. Surgeons relying on teleoperated systems demand very low communication latency and very high reliability. Technical failure at any point in the system can have catastrophic consequences. Further, the costs of maintaining such infrastructure are high. For these reasons, the application of telemedicine in this field has been limited to the experimental level. Several successful case studies have elaborated on the benefits, challenges, and limits of remote surgery being conducted with robotic surgical systems. A robot-assisted endoscope holder also supported a two-day surgical mission to perform complex tumor ablation in severe head and neck cancer patients. Such systems were able to integrate into the surgical suite to provide surgical imaging, were easy to use, integrated within the surgical suite, and provided good situational cognitive support to the remote surgeon.

From an ethical standpoint, the legal aspects of providing patients with full information about the procedure, the abilities and limitations of the technology itself, and the risks of transmission failure should be tackled. A significant problem is remote postoperative care as the surgeon may not stay near the operating room or the patient after the surgery. Nevertheless, with the incorporation of telehealth services into robotic-assisted surgical services, greater access to surgical expertise is made possible. More and more, urban residents receive elective surgeries with a remotely based surgical team. Expanding telehealth to provide access to surgical care could help to create a global public health infrastructure.

Research to support large-scale programs is required to reduce information gaps and knowledge to help guide strategies for safe, comprehensive integration of surgery into universal telehealth programs during pandemic-oncologic disasters. Overall, to progress telehealth as a sustainable public health initiative, advocate responsibility, provision of ethics, and safety knowledge for remote surgeons across multiple platforms, and work in partnership to create integrated telehealth centers.

6.4. Benefits and Challenges of Robotics and AI in Surgery

Like other applications, the use of robotics and AI can be beneficial in surgery. Robots can be programmed to perform tasks with a higher degree of precision and accuracy than a human hand, which is particularly useful during intricate operations. AI can also analyze sophisticated data with high accuracy, making AI systems useful in diagnostic and predictive roles. Both robotics and AI are useful in minimizing human error by bringing greater accuracy and increasing safety for patients. These technological tools can be used to learn from large volumes of historical case data to inform better courses of action, improving clinical outcomes. The result can be shorter hospital stays, faster recovery times, and fewer complications—all improvements for the patient. There is therefore considerable research interest in robotic surgery, and procedures that have been performed with a robot or which have been supplemented by AI input include joint surgery, dental procedures, robotic exoskeletons, physiotherapy, and cardiovascular repair. This said several barriers need to be overcome for surgical robotics and AI to become the norm. It is a challenge for the medical profession to update training and support infrastructure to facilitate these clinical innovations so that currently practicing surgeons are equipped with the skills and knowledge to benefit from these advancements. Surgeons need to develop an understanding of the ethical considerations in this field, in terms of seeking informed consent for AI-augmented surgery, to ascertain where ultimate responsibility and liability lie in robot-performed or robot-guided operations (Sondinti et al., 2023). Moreover, in light of predictions of how surgical options will continue to evolve, there is a risk of becoming over-reliant on robotic surgery in clinical practice to combat the inevitability of errors during interventions, which, in a society that asks for perfect outcomes, is an understandable human impulse. We also need to recognize how AI and robotics will reshape the surgical profession—with robots becoming 'colleagues' rather than tools, decisions are no longer primarily made by the surgeon, surgery teams become smaller, and AI can assist with decision-making, thereby reducing the otherwise overwhelming knowledge burden of the human surgeon.

6.4.1. Precision and Accuracy

One of the main advertised advantages of using robotics in surgery is improved precision and accuracy. Greater precision is particularly useful in complex surgeries where such ability could avoid harming delicate tissues or vital structures. Moreover, improved accuracy may also be beneficial in reducing side effects or identifying unnoticed problems. Besides robotic assistance in the operating room, AI has also been increasingly used in preoperative planning and intraoperative decision-making. Many AI-driven planning tools have reached a performance level comparable or even superior to their human counterparts, usually by rapidly analyzing and suggesting optimally tailored solutions. During the surgery, surgeons can make use of AI technologies' recommendations to adjust their actions by improving the overall sense of precision. An interesting AI-based application has also been developed for liver surgery that provides surgeons with visual feedback on the quality of the cut being performed and whether there is a risk of causing bleeding.

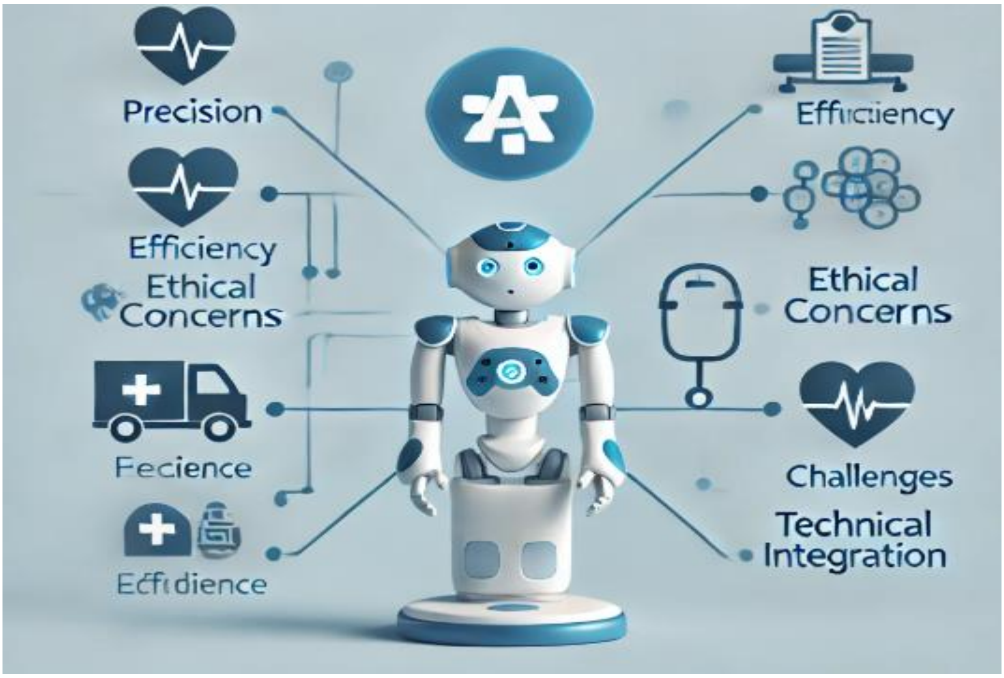

Fig 6 . 3 : Robotic Surgery in Modern Healthcare: Benefits and Challenges.

Highly relevant to precision is also the aspect of control and feedback that most robotic surgical systems provide. Indeed, in robotic systems, feedback sensors are instrumental in ensuring safety and precision. Data obtained from these sensors can be used in real-time by the surgical system to accommodate tissue motion, tool interactions, or even the physical sleep of the user. In addition, these data can be pooled together to monitor skill acquisition. Although this feedback raises a wide array of control-related topics on its own, some studies notice an intriguing potential in utilizing this data to automatically upgrade manipulative skills via machine learning. Furthermore, some studies are showing near-perfect intra-procedure accuracy in image-guided robotic-supported cochlear implant insertion. However, there are challenges in quantifying precision (Vankayalapati et al., 2023). A common problem is the lack of a reference standard or having a truly independently verified reference standard, such as imperceptible tissue damage. The range of surgical expertise in using robotic systems can also be a challenge. Technical glitches are common and can provide a wide range of either negative or positive effects, exemplified by the distraction and failure of the robotic system due to extreme local tissue reactions. Almost all the evidence is from feasibility and simulation studies. The results from a few case reports are, however, rather spectacular, leading to some successful new treatment modalities or patient-friendly approaches therein. Some interventions highlighted are associated with potentially severe complications when performed using conventional techniques.

6.4.2. Improved Patient Outcomes

Robots, in the hands of highly skilled clinicians, have already demonstrated decreases in the time required for a patient to return to presurgery activity, with a 25%–60% decline in length of stay and a five-times decrease in complications as a result of adopting minimally invasive robotic surgery for those surgeries for which it is approved compared with non-robotic surgery. This is especially meaningful for types of surgery that are most at risk for complications, lead to longer hospital lengths of stay where the decline was most significant, and subsequently yield the highest rates of acute care readmissions in the first month following surgery. In the case of cholecystectomies, major complications requiring hospital readmissions decreased from 6% to 1% for robotics-assisted cholecystectomies compared with those without the use of robots. Robotic-assisted surgery patients used significantly fewer opioids before hospital discharge and reported lower levels of pre-and postoperative pain, suggesting less stress on organs, tissues, and the body during identical surgeries despite differences in surgery duration. Robotic bariatric surgery patients, while no different in total complications from non-robotic surgery, experienced a reduction in 'severe intraoperative complications,' a statistical finding interpreted as resulting from reduced tissue manipulation and the ability to avoid damaging fatty structures with robotics assistance. To the patient, these findings may mean they can experience feelings of being healthy again in a fraction of the typical time, experiencing the consequences that may include less pain and the need for strong prescription medication with its side effects, less visible and cosmetic disfigurement, and a quicker return to normal life activities. After surgery, consistent real-time monitoring of all available patient information, including preadmission health status and support systems, important social determinants of health such as housing and nutrition, anesthesia, and vitals throughout a stay, can be submitted to AI analytics to rapidly identify anything of concern according to unique backgrounds or materials used to comply with care plans and administrative procedures. This information can inform the care team of likely patient responsiveness post-discharge; the risk of readmission in the next 30 days; the care transitions to be made at the point of discharge; how the hip chosen is healing according to unique health and lifestyle; and previously hidden or ignored complications of surgery.

Highly variable quality and safety outcomes affecting both the patient and health system results, however, due to divergent levels of surgeon experience, are an unintended, though predictable, consequence of any disruptive technology. This is not unique to robotics adoption in practice; variability is a given in human medicine. In inpatient care, any outsized optimism regarding utilizing robots for 'safer and better' surgical outcomes requires ethical scrutiny. Unfortunately, some believe that a robot infers 'no human error'; discouragingly, one survey found a huge level of unawareness among patients who thought robots were autonomous. Informed medical device consent is based on respect for self-determination, recognizing autonomy and the right to refuse or accept proposed medical treatment or medical research, and the need to protect those with diminished autonomy. In research with human beings, informed consent protects not only the rights and welfare of the trial volunteers but also advances the trust and recruitment of future volunteers. Patient engagement in their healthcare, including a full understanding of the use of AI in their surgical care, is key to creating a healthcare delivery system that is responsive to both the needs of the patient and the general public that supports it.

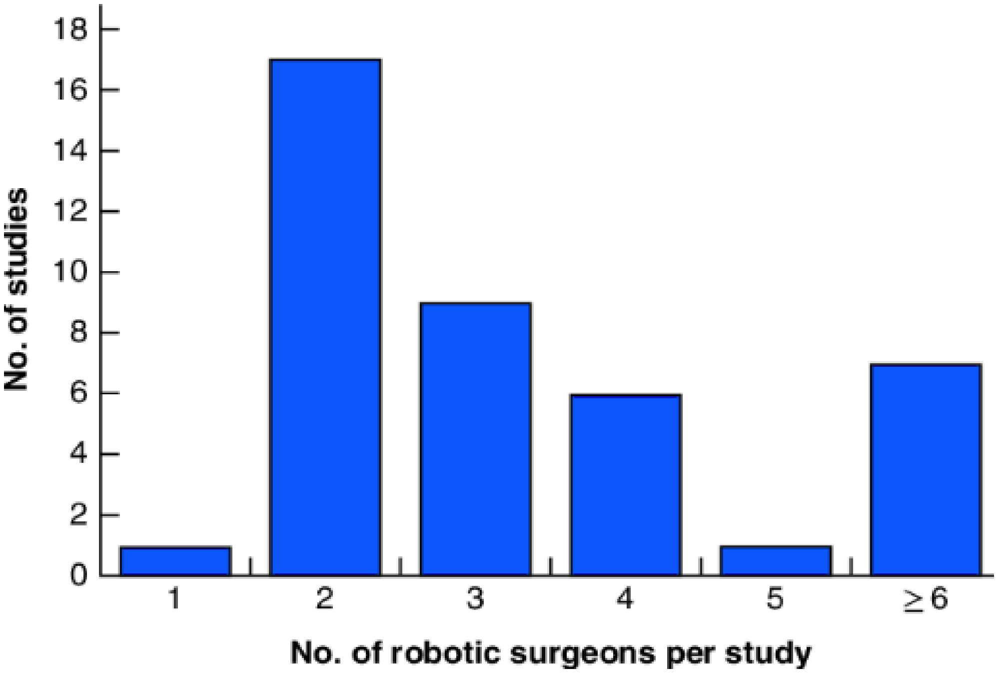

Fig 6 . 4 : Robotics and AI in Surgery.

6.4.3. Ethical and Legal Considerations

From an ethical point of view, the introduction of robotic systems in the operating theatre alters the entire process of personalized healthcare, requiring in-depth analysis to address all the dilemmas. It is unclear how to proceed in case a patient is harmed while being operated on using a robotic system. All robotic surgeries are performed under the supervision of a member of the medical team who is ultimately responsible for the patient. However, if it comes down to liability, it is unethical for surgeons to simply point at the robot manufacturer or at the healthcare institution that owns the AI system. In the healthcare sector, surgeons cannot simply blame the robotic system or AI analytics that determined the diagnosis or treatment for the patient, as it was they or the institution that offered that device as a prospective treatment option or partnered with the AI data analytics company. A regulation determining the conditions of liability in distributed diagnosis between AI data analytics providers, healthcare providers, and patients must be issued according to the Product Liability Directive. One of the major concerns with AI analytics and medical robotics is the processing of extensive volumes of sensitive personal data. To perform well, AI technology requires extensive datasets for analysis, which can result in ethical and legal problems if not managed properly (Maguluri et al., 2022).

Nonetheless, there has been an increasing awareness that errors in algorithms or bad databases can cause datasets to be biased and enforce established or the majority class, whether genotypically, phenotypically, symptomatically, or pathologically. Such biases are unintended or unintentional and can pose serious hazards to the patient if the clinical decision or therapeutic means are based on such data. Several regulations suggest that the algorithms have to be explained, including the data used, the mathematical models, and the theories, to understand how the algorithms conclude. It is important to educate patients and surgeons regarding the AI algorithms used in the robotic system as well as machine learning models, in particular, if the decision is taken automatically, so the patient can agree to the procedure based on the AI advice or choose not to go for surgery or to suggest another method of treatment. Ultimately, the key issue for those performing legal and ethical analysis is whether robot-assisted surgery constitutes harm – not in the sense of legitimate, non-malicious, unpreventable complications as with any surgical procedure, but in the sense of deceptive enrichment and illegitimate, unacceptable malpractice. We wholeheartedly concur and share the duty to engage in a far-reaching critical dialogue to ensure that robotic surgery and AI in surgery are part of that ongoing and undeviating progress toward ever-greater medical efficacy and safety. Regulation has to come into play to allow potential patients to trust the systems that care for them.

Equation 3 : Image-Guided Surgery (Registration Error):

$$E_r = \|P_s - P_i\|^2$$

E_r: Registration error,
P_s: Sensor-based position,
P_i: Image-based position.

6.5. Future Directions and Innovations

The future of robotics in surgery is difficult to predict as technological advances may lead the field in unexpected directions. Nevertheless, it is reasonable to argue that machine learning and new surgical AI algorithms will have a major role in the future of surgery. Machine learning involves the development of algorithms that can improve their performance, accuracy, and reliability over large datasets. Potential benefits involve enhanced decision support, personalized surgery, better metrics and accounts of surgical skill, innovative patient-specific models, or improved haptic feedback systems. Combining AI techniques with neuro ergonomics, human-computer interaction, human factors, cognitive sciences, or decision neuroscience may offer reliable and objective feedback systems for monitoring surgeons during procedures, informing them about the limits of abilities, or determining personalized training pathways. These efforts, in-depth and overview, involve managers and numerous players. Ideally, multiple surgical communities should meet to introduce interdisciplinary perspectives and to share experiences, strategies, pros, and cons. Despite the efforts, it should be emphasized that acknowledgement from patients is crucial, and further clinical and experimental investigations are needed to move from the prototype to the widespread application. Patient safety is a priority.

Augmented reality, virtual reality, and simulation technologies can revolutionize the way we educate and train surgeons. Augmented reality and virtual reality offer realistic, three-dimensional environments and can provide surgeons with 'immersive' virtual surgery training. The development of these venues is an ongoing effort. Research into augmented reality and virtual reality applications in surgery will continue, involving collaboration between technology developers, and clinicians, and thorough evaluation of the effectiveness and acceptance of these new technologies. Ensuring that these applications are effective, realistic, and relevant is paramount to their potential success. It is also important to consider simulation within augmented reality and virtual reality surgery. There are continuous areas of development in these fields, including the integration of kinematic or force feedback into augmented reality and virtual reality scenarios to make them not only visually but also physically realistic, and to assess the application of augmented reality to robotic surgery, targeting faster technological advances and commercial exploitation. Ethical considerations are needed, for example, with AI, when does the neuro ergonomics system 'learn' more about the end-users than the end-users themselves know? Clear monitoring and interfaces will need to be developed to safeguard against potential misuse such as unauthorized access to sensitive information.

6.5.1. Advancements in Machine Learning and AI Algorithms

AI systems and their possible applications can greatly influence surgery in the future. The robotic platforms used in surgery are generally controlled by clinicians, and some tasks are already automated. Other possible approaches include the use of AI models to provide real-time advice and surgical support, to enhance operating room monitoring, to design robots, to decide on robotic path planning, or to determine the actions of a robot. In addition, improvements in the software and robotic systems of the operating room are also discussed, such as automatic systems for suture, stapling, and retractor placement, and neuromonitoring systems to reduce nerve injury during surgery. In summary, artificial intelligence algorithms are aiding in improving many areas of machines, such as robotic systems. Ideally, AI systems should provide useful feedback, which will directly contribute to a slower yet safer approach in certain operations. Advanced machine learning algorithms, such as deep learning, are increasing the capabilities of robotic systems and are continuing to be enhanced. For improved patient outcomes and safety, advancing robotic systems and machine learning algorithms will rely on a large selection of surgical datasets depicting variations in surgical techniques and can be implemented in a clinical setting, in which machines are endoscopic and are controlled via physical robots. Although clinical validation and elimination of computational errors still need to be solved, these approaches will allow robust interaction and will provide real-time feedback to the surgeon during surgery.

6.5.2. Integration with Augmented Reality and Virtual Reality

Finally, robotics and AI can be combined with human-computer interfaces in augmented reality and virtual reality, integrating information and technologies to improve data visualization and analysis. These techniques use either headsets or screen-based visualization tools to enable surgeons to visualize a virtual surgical scenario, including the interaction with anatomical elements in real-time. Augmented reality can benefit preoperative planning by allowing surgeons to move and manipulate 3D anatomical models and can facilitate interactive guidance and pointing, thus enabling better preoperative planning and guidance. This immersive and interactive experience with the various devices during procedures is in the prototyping phase. Virtual reality can completely immerse the surgeon in the virtual scenario, so it can be used in surgical training to empower the surgical team in facing complex procedures.

Moreover, virtual reality can be tested for training surgery residents in many minimally invasive telesurgery programs, such as in robotic programs where the instruments are manipulated, a condition that can be emulated with virtual reality. However, this area is still under heavy testing for limitations. First, these technologies seem to be disconnected from the complex surgical scenario, adding another layer of complexity that may not match the current surgical workflow. Second, an enormous amount of extra training must be provided to surgeons to deal with the new features connected to these technologies. Third, a lot of basic biocompatibility features must be tested, such as the risk of short- and long-term cybersickness and surgeons' symptoms that could reduce the safety and effectiveness of the surgical action. Overall, the combined intraoperative visualization, augmented reality/virtual reality, and robotics and AI is a breakthrough for the future of surgery. However, there is an urgent need to conduct clinical studies to understand the effect on surgical parameters and the end outcome.

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