AI-Driven Robotics has Optimized Motion Control, Decision-Making, and Real-Time Adaptability in Minimally Invasive Surgeries: A Systematic Review

Mary Little Flower Thomas[1], Christopher Ezhil Singh Sreedharan[2], Glan Devadhas George[3], T. Jaya[4], Sridharan Ponnusamy[2], Jerril Gilda Sreedharan[5], S. Jerril Gilda[6], K. G. Jaya Christiyan[7] and M. P. Muhsin[2]

[1]Department of ECE, St. Xavier's Catholic College of Engineering, Kanyakumari, Tamil Nadu, India
[2]Department of Mechanical Engineering, Vimal Jyothi Engineering College, Kannur, Kerala, India
[3]Directorate of Research and Innovation, CMR University, Bengaluru, Karnataka, India
[4]Department of ECE, Saveetha Engineering College, Chennai, Tamil Nadu, India
[5]Department of Mechanical Engineering, Rajalakshmi Engineering College, Chennai, Tamil Nadu, India
[6]Department of EEE, Sri Muthukumaran Institute of Technology, Chennai, Tamil Nadu, India
[7]Department of Mechanical Engineering, M. S. Ramaiah Institute of Technology, Bangalore, Karnataka, India

Correspondence to:
Mary Little Flower Thomas, mlitleflower@gmail.com

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ABSTRACT

Artificial intelligence (AI) and robotics have transformed patient treatment, diagnosis, surgical intervention, and the health industry. Robotic-assisted devices enhance procedural success, minimize recovery times, and maximize surgical precision. Motion control, decision-making, and real-time responsiveness in minimally invasive surgery have all been enhanced by the application of AI-based automation. Teleoperated robotic devices have enhanced access to specialist medical information through remote operation and expanded access to healthcare. In addition to these innovations, exorbitant costs, training, ethics, and cybersecurity issues continue to hamper developers from mass applications. These concerns must be addressed to ensure the safe, effective, and ethical use of robotic healthcare systems. To improve surgical performance, future research should focus on creating affordable alternatives, improving robotic dexterity, and integrating AI-based decision support. Robotic healthcare technologies will revolutionize healthcare delivery worldwide with future developments, improving the precision, accessibility, and efficiency of advanced medical interventions in the future.

Keywords: AI-driven motion compensation, Teleoperated robotic surgery, Haptic force feedback, Deep learning instrument segmentation, Cybersecurity in surgical robotics

Introduction

The robotics and artificial intelligence (AI) has transformed medical diagnosis, procedures, and patient care. Predictive analytics based on AI, robotic-assisted surgery (RAS), and minimally invasive surgery (MIS) have transformed the accuracy, productivity, and patient outcomes to a much greater extent. Clever robots are being used increasingly in healthcare owing to ongoing technological advancements, which have overcome essential challenges such as motion compensation, remote-controlled procedures, and autonomous surgical procedures. Focusing on teleoperated surgical systems, robot-assisted diagnostics, and MIS, this paper describes the developments, applications, and possible future of AI and robotics in healthcare. MIS is an important area of robotic integration that offers greater patient dexterity, accuracy, and lower trauma than conventional surgery. Through multiple studies regarding the use of robots in esophectomy, colorectal, and liver excision surgeries, it has also been revealed that the production of smart robot systems in MIS has enhanced the outcomes of a surgery.[1] Robot-assisted systems have been additionally demonstrated to perform better than conventional laparoscopy in complicated and highly-precise procedures (e.g. the da Vinci Surgical System).[2] Moreover, AI has enabled simultaneous teleoperation that integrates force and real-time directing allowing surgeons to enhance their work.[3]

According to Figure 1, the growing popularity of surgeries that are carried out by the robot platforms to which they are attached is an indicator that AI-based robots are becoming more commonly used in the medical sector. The researchers identified a short patient recovery time, fewer postoperative complications, and accuracy during surgery as some of the most robot-assisted MIS trends and advantages.[4] AI algorithms are necessary to maximise the range of movement of that robot, compensate for any movement during physiological movements, and decisions are more efficient when it is applied during intraoperative procedures.[5] The use of deep learning and generative neural networks to segment instruments in surgery ensures maximum efficiency of the surgery process, reduces human error, and allows surgeons to automate the most complex cases.[6] Teleoperated robotic surgery is currently a lifesaver for remote surgery, especially in emergency situations and geographically remote places. To empower surgeons operating in distant settings to have unrivaled accuracy and control, scholars have experimented with and institutionalized multi-robot systems in teleoperated minimally intrusive surgical operations.[7] With remote telementoring frameworks and telerobotic neurovascular interventions, master surgeons can now instruct students and practitioners to perform their endeavors in the farthest corners of the world.[8–10] Such technologies are indicative of how AI and robotics may improve the training of surgical workers and make specialist care available.

Although these developments are on the rise, concerns remain regarding the safety, faithfulness, and ethical application of AI-driven robotic systems in medicine. For example, autonomous robot surgery increases patient safety, accountability, and transparency of decision-making.[11] Robust cybersecurity is required for robot-assisted medical devices because of their greater reliance on networked systems and cloud-based AI models. Future research efforts should be directed toward improving real-time adaptation, incorporating augmented reality (AR) for enhanced visualization, and creating more autonomous but ethical robotic systems as AI and robots continue to transform

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healthcare. The future generation of intelligent medical technology will be defined by the convergence of AI, robots, and healthcare practitioners to provide safer, more efficient, and more accessible healthcare solutions to patients globally.

The integration of RAS into minimally invasive procedures represents a paradigm shift in modern surgical care. The review combines the results of the major studies conducted by Nagarkar et al.,[12] Ng et al. (2023), Lee et al.,[13] Fong et al.,[14] Dagnino and Kundrat,[15] and industry data published by Intuitive (2025), to review the clinical, economic, and accessibility effects of robotic systems in different fields of surgery.

Literature Review

Robotics and AI are used in medicine to transform the way it is practiced nowadays. Improving the precision, effectiveness and access of surgical and diagnostic therapies has been a central research concern in this area. This literature review covered robot-assisted surgery, motion compensation, minimally invasive surgical robots, teleoperated systems, safety and ethics of AI-based medical robotics.

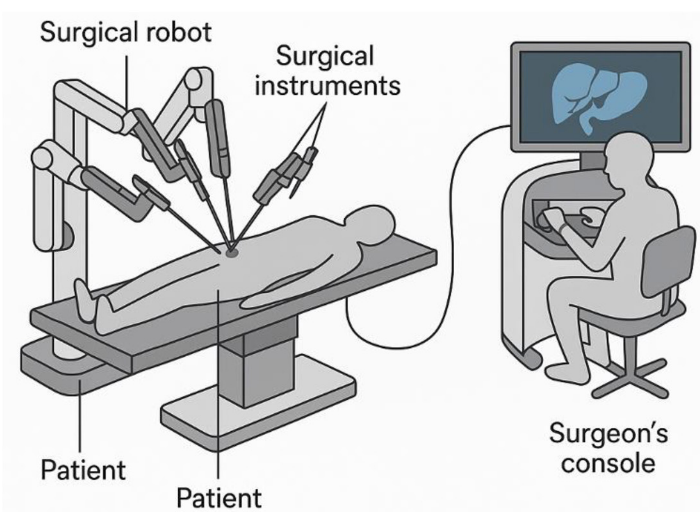

Fig 1 | The surgical robots in healthcare

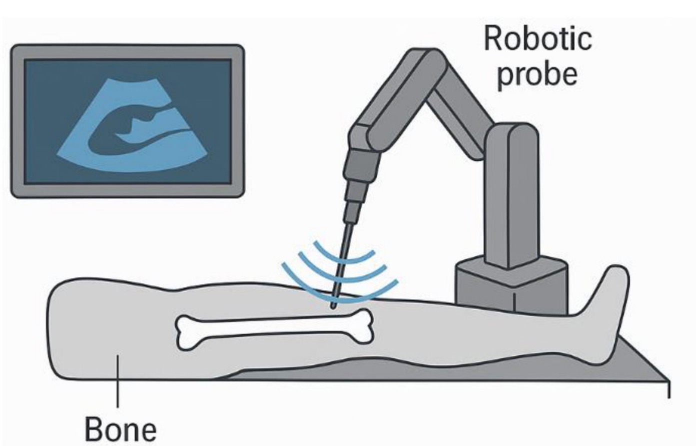

Fig 2 | The robotic motion compensation for bone movement using ultrasound images

Figure 2 shows how Torres et al.[5] applied ultrasound images to study the robotic motion compensation of bone motion and stressed real-time correction to surgical precision. Klodmann et al.[16] also stressed how AI would enhance surgical results through adaptive algorithms, reduce human errors, and enhance robotic mobility. Sheetz et al.,[4] who demonstrated reduced recovery time and fewer postoperative complications, underscored the increased utilization of robotic surgery in standard procedures.

Meinzer et al.[17] analyzed trends in pediatric MIS, stressing the growing role of robotic systems in enhancing precision and safety in delicate procedures. Kiani et al.[18] explored direct-to-consumer advertising of robotic heart bypass surgery, finding a positive correlation between patient satisfaction and robotic-assisted procedures. van Boxel et al.[1] discussed the evolution of robotic-assisted esophagectomy, assessing its feasibility, safety, and future potential.

Leporini et al.[7] validated a teleoperated multi-robot platform for MIS as shown in Figure 3, proving its efficacy in remote surgical interventions. Kim et al.[8,10] demonstrated the viability of telerobotic neurovascular interventions with magnetic manipulation, paving the way for real-time robotic-assisted procedures in distant locations. Fujie and Zhang[19] reviewed the state-of-the-art developments in intelligent minimally invasive surgical robots and identified key improvements in robotic dexterity, force feedback, and real-time AI processing. Azqueta-Gavaldon et al.[6] applied generative deep neural networks to segment surgical instruments, demonstrating AI's capability of AI to automate complex medical tasks. Patel et al.[3] analyzed haptic feedback and force-based teleoperation in surgical robotics, emphasizing their roles in enhancing surgeon control. Nguyen et al.[20] explored advanced user interfaces for teleoperated surgical robotic systems, highlighting developments in intuitive control mechanisms and real-time decision support.

Thiruvenkdam et al.[11] assessed cybersecurity risks in minimally invasive robotic surgeries as shown in Figure 4, addressing potential vulnerabilities in AI-driven systems. Runciman et al.[21] examined soft robotics' role in surgical applications, discussing the implications of flexible robotic technologies in improving safety and adaptability. Xue et al.[2] compared robotic and laparoscopic surgeries in elderly patients with colorectal cancer and demonstrated superior outcomes with robotic intervention. Kim et al.[8,10] explored advancements in flexible robotic technologies for endoluminal surgeries, highlighting improvements in dexterity and adaptability. Boehm et al.[22] reviewed the current advances in robotics for head and neck surgery, emphasizing the role of autonomous robotic platforms in complex anatomical procedures.

Lajkó et al.[23] introduced an endoscopic image-based skill assessment in robot-assisted MIS, as shown in Figure 5, demonstrating the application of AI in evaluating surgical performance. Yazicioglu and Borat[24] reflected on the evolution of surgical robotics and

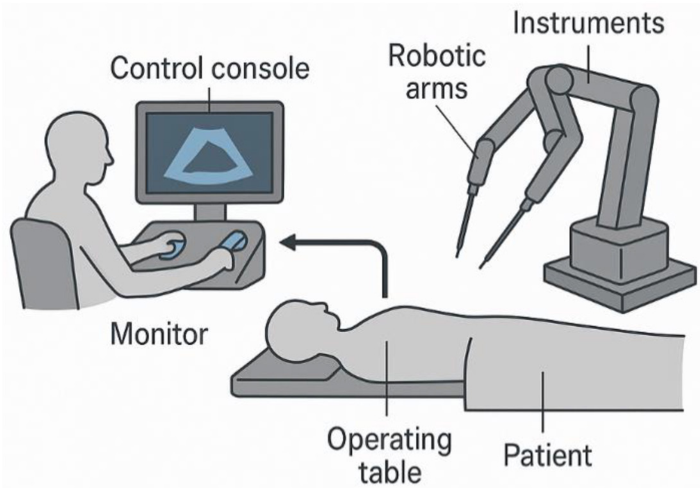

Fig 3 | The teleoperated multi-robots platform for MIS

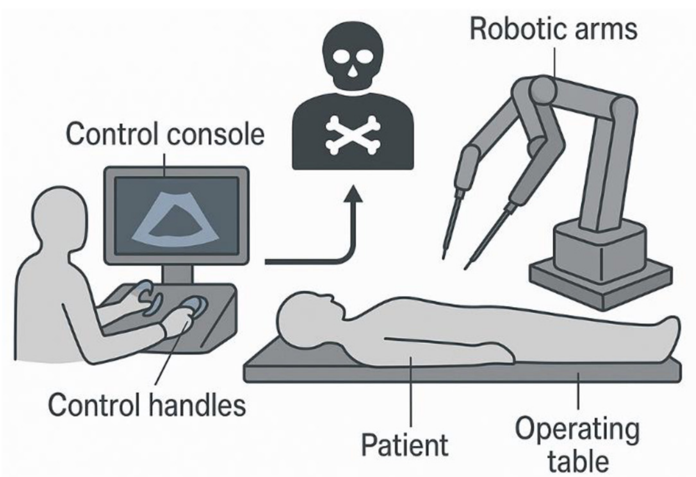

Fig 4 | The cybersecurity risks in minimally invasive robotic surgeries

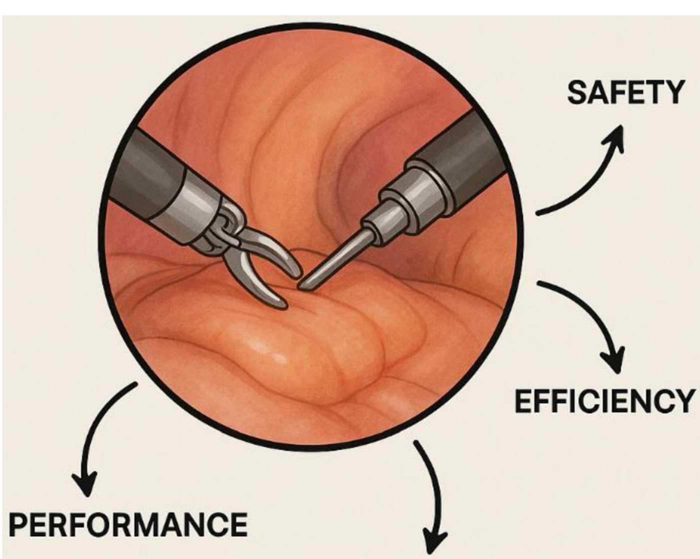

Fig 5 | The endoscopic image-based skill assessment in robot-assisted MIS

provided insights into the latest breakthroughs and challenges in AI-assisted diagnosis.

Shabir et al.[9] evaluated a preliminary design for a remote tele-mentoring system in MIS and assessed its impact on medical education and training. Tonutti et al.[25] examined the role of technology in MIS, identifying AI-powered training tools that improve surgeon proficiency and accuracy. Haidegger[26] and Fujie and Zhang[19] explored the future of surgical robotics in the age of data and predicted advancements in AI-driven automation, AR integration, and improved real-time analytics. Xue et al.[2] evaluated robotic and laparoscopic surgeries in elderly patients, reinforcing the long-term advantages of robotic surgical platforms.

Nagarkar et al.[12] present a single-center retrospective study on robotic-assisted minimally invasive esophagectomy (RAMIE) using the Versius system. Their results from 52 patients demonstrate a median operative time of 111.6 minutes, minimal blood loss (40 mL), and a 30-day mortality rate of 3.85%. The study underscores the safety and feasibility of RAMIE, attributing improvements to refined techniques and better system integration. These findings align with earlier studies, such as the ROBOT trial, though the authors acknowledge a learning curve affecting initial outcomes.

Lee et al.[13] provide a comprehensive review of navigation-guided and robot-assisted spinal surgery. They emphasize the enhanced accuracy of pedicle screw placement, reduced radiation exposure, and shorter learning curves associated with systems like Mazor X, ROSA, and ExcelsiusGPS. However, they caution that long-term clinical benefits and cost-effectiveness remain understudied, calling for more robust evidence before widespread adoption.

Zhi Ven Fong et al.[14] and the Intuitive Surgical address the role of RAS in expanding access to MIS, particularly in underserved "MIS deserts." Fong's study of 408 U.S. hospitals shows that RAS introduction increased MIS rates from 60.5% to 65.8%, with significant gains among older patients and those with Medicare or commercial insurance. The study argues that RAS mitigates barriers such as surgeon training limitations and ergonomic challenges of laparoscopy.

As Dagnino and Kundrat[15] put it, the history of robotic MIS begins with primitive systems such as PUMA 200 and da Vinci and ends with such current systems as Versius and Hugo RAS. They emphasize developments in imaging, sensing and human-robot interaction, such as haptic feedback and AI based autonomy. Micro- and nanorobots, the authors project, allow interventions at the cellular level in the future, but they are not without serious translational challenges, including safety and regulation, and acceptance in clinical practice.

In the study of spine surgery, Bunch et al.[27] describe the symbiotic relationship between navigation, robotics, AR, intraoperative imaging and MIS. The authors note that these technologies are not independent innovations, but tools that complement each other to increase accuracy in surgery, decrease the load on cognition, and improve patient safety. An example would be that AR and navigation systems reduce the number of error instances as they reduce the attention shift between the surgical field and the monitors. Robotic aid enhances the accuracy of pedicle screw placement and preoperative planning modules with patient-specific data maximize the results in multifaceted deformity. Nevertheless, there are still obstacles to overcome, such as high expenses, learning curves, and the necessity of a smooth integration into workflow. The authors conclude that the convergence of these technologies is the future and that it is facilitated by AI and enhanced user interfaces.

Scheese et al.[28] provide a review of the development of esophagectomy as an open (OE) and minimally invasive (MIE) or robotic-assisted (RAMIE) procedure. RAMIE is more dextrous, three-dimensional, and tremor-filtered, solving the problems of traditional MIE: hard tools and high learning rates. The authors conclude that RAMIE minimises intraoperative blood loss and yields better lymph nodes than OE, but the duration of operation is prolonged. The rates of anastomotic leak depend on RAMIE and MIE are similar, as well as other complications. Significantly, the learning curve of RAMIE (36 cases) is shorter than that of MIE (69 cases), which indicates faster learning to become proficient. The price is still a challenge, yet lower complication rates are likely to balance the start-up costs. The authors propose the use of RAMIE as a safe, viable, and more popular method of treat esophageal cancer.

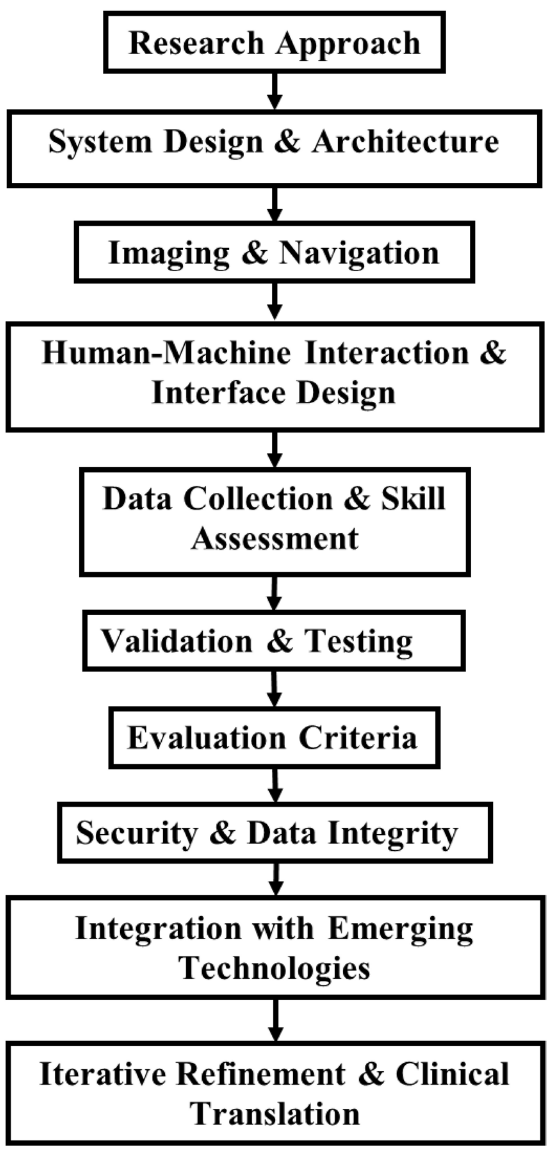

Fig 6 | The flow chart on methodology for RAMIS systems

Lefor et al.[29] respond to the problem of the availability of training resources in robot-assisted liver surgery. They design and test a virtual reality (VR) simulator that presents kinematic information, including path length, time and number of movements, as an objective measure of surgical skill. The simulator draws a distinction between experts and novices and the experts are the ones that show a shorter path length, fewer moves and shorter time. Participants rated the educational value, interfaces and the simulator as very realistic. This study underscores the potential of VR simulation to supplement traditional training, especially in fields where robotic systems are costly and data access is limited. The authors highlight the importance of kinematic metrics in skill assessment and the role of simulation in democratizing surgical education.

Zaman et al.[30] conduct a meta-analysis comparing robotic and laparoscopic colorectal resections in IBD patients. They find that robotic surgery is associated with significantly fewer total postoperative complications, though operative times are longer. Conversion rates, anastomotic leaks, surgical site infections, and other secondary outcomes are comparable between the two approaches. Length of stay is shorter for robotic subtotal colectomies. The authors note that robotic platforms offer technical advantages in complex pelvic dissections and intracorporeal anastomoses, potentially leading to better functional outcomes. However, long-term data on quality of life and cost-effectiveness are lacking. The study concludes that robotic surgery is safe and feasible for IBD, with a trend toward superior outcomes as surgeon experience grows.

Methodology

Development and Evaluation of Robotic-Assisted Minimally Invasive Surgery (RAMIS) Systems

Research Approach

RAMIS combines robotics, imaging, sensor technology, and surgical expertise to enhance precision, reduce invasiveness, and improve patient outcomes. Figure 6 shows the methodology developed herein to analyze, validate, and optimize robotic surgical systems in terms of technical performance, clinical safety, usability, and integration with advanced features such as AI, haptics, and teleoperation. This approach is divided into multiple phases: system design, data acquisition, system validation, performance evaluation, and clinical integration phases.

System Design and Architecture

The system design included the hardware and software development of the surgical robotic platform. The components typically consist of the following:

Master Console (Teleoperation Interface)

Controlled by the surgeon to send commands to the robotic arms.

Robotic Arms/Manipulators

Perform surgical tasks using end-effectors and tools.

Vision and Imaging Systems

Often include 3D endoscopes and real-time imaging via ultrasound or fluoroscopy.

Haptic and Force Feedback Modules

Enhance the surgeon's control and sensory perception.

Flexible Endoscopic Components

For endoluminal surgeries.

AI-based Image Processing and Instrument Segmentation

Deep learning networks are used for object detection and surgical scene understanding.

The software architecture includes surgical planning modules, control algorithms, safety features, and feedback integration.

Imaging and Navigation

Preoperative Imaging

CT, MRI, and ultrasound are used for mapping the anatomy and planning the procedure.

Intraoperative Guidance

Real-time image tracking and robotic motion compensation to adapt to organ movement.

Instrument Tracking and Segmentation

AI models, such as generative deep neural networks, are used to identify surgical tools and anatomy structures.

Human-Machine Interaction and Interface Design

User Interfaces

Interfaces are designed with ergonomic considerations, real-time feedback loops, and visual overlays to assist the surgeon.

Teleoperation and Remote Surgery

Systems are tested for latency, fidelity, and control in tele-surgical applications.

Haptic Feedback

Simulated tactile sensations are integrated to enhance the realism of remote procedures.

Data Collection and Skill Assessment

Simulation Environments

Virtual and physical simulators were used to gather performance data under various surgical scenarios.

Endoscopic Image-Based Evaluation

Robotic surgeons are assessed in terms of objective metrics derived with video and tool trajectory data.

Sensor Data Logging

The sensor data were logged in terms of force, position and timing to test the control accuracy and user interaction.

Validation and Testing

Bench Testing

Initial testing of the system in controlled laboratory conditions with synthetic models or phantom tissues was done.

Animal Trials

Where appropriate, systems are evaluated in animal models for preclinical testing.

Human Pilot Trials

Conducted under ethical approvals, focusing on feasibility, safety, and efficacy.

Evaluation Criteria

The system performance was measured using several metrics:

Accuracy and Precision

Measured using trajectory deviation, task completion time, and error rates.

Safety and Reliability

Assessed via adverse event rates, motion compensation efficiency, and robustness to system faults.

Usability

Surveys and observational studies to gauge user satisfaction and ease-of-use.

Clinical Outcomes

Compared with conventional laparoscopic or open surgery in terms of recovery time, blood loss, and complications.

Security and Data Integrity

Cybersecurity Protocols

Protection against unauthorized access and command spoofing, especially in autonomous or remote systems.

Data Logging and Privacy

Ensures encrypted storage and access compliance with medical data standards.

Integration With Emerging Technologies

AI and Soft Robotics

For intelligent control and tissue interaction.

Tele-Mentoring Systems

Integration of real-time communication and guidance tools to support remote surgical training.

Magnetic Manipulation

Applied in neurovascular interventions for precise, non-contact tool navigation.

Iterative Refinement and Clinical Translation

After validation, the system underwent iterative design improvements.

Regulatory pathways (e.g., FDA, CE) are followed to move from the prototype to the commercial system.

Post-market studies and feedback loops were established to monitor real-world effectiveness.

Results and Discussion

Robot-assisted healthcare have significantly improved surgical precision, patient outcomes, and procedural efficiency. Table 1 shows the comparison of robotics and automation on AI in surgery. The integration of AI into robotic systems has led to enhanced automation, real-time decision-making, and superior adaptability in MIS. Several studies have analyzed the impact of robotics in surgery, indicating reduced recovery times, minimized complications, and improved accuracy in complex medical interventions. One of the primary results observed is the significant enhancement

Table 1 | Comparison of robotics and automation on AI in surgery

Reference	Focus Area	Key Findings	Limitations
Torres et al.,[5] Klodmann et al.[16]	Robotic Motion Compensation and AI-Assisted Surgery	AI improves precision, reduces human error in complex surgeries	Requires real-time imaging, high computational requirements
Sheetz et al.,[4] Meinzer et al.[17]	Trends and Adoption in Robotic Surgery	Increasing adoption improves patient recovery, enhances pediatric safety	Expensive implementation, limited accessibility
Kiani et al.,[18] van Boxel et al.[1]	Patient Satisfaction and Surgical Efficiency	High satisfaction rates, improved safety in robotic esophagectomy	Marketing bias, specialized training required
Leporini et al.,[7] Kim et al.[8,10]	Teleoperated and Telerobotic Surgery	Enables remote minimally invasive procedures, magnetic manipulation for neurovascular interventions	Dependent on network stability, limited real-world testing
Zhu et al.,[31] Fujie and Zhang[19]	Intelligent Surgical Robots and Instrument Segmentation	AI-driven automation enhances dexterity, deep learning automates instrument detection	High development costs, requires large datasets
Patel et al.,[3] Nguyen et al.[20]	Haptic Feedback and User Interfaces	Improves precision, enhances usability of teleoperated systems	Expensive hardware, requires extensive training
Thiruvenkdam et al.,[11] Runciman et al.[21]	Security and Soft Robotics in Surgery	AI-driven systems require cybersecurity, soft robotics enhance adaptability	Potential cyberattacks, less rigid control than traditional robots
Xue et al.[2]	Robotic vs. Laparoscopic Surgery and Advanced Procedures	Robotic surgery improves outcomes in elderly, feasibility in colorectal and liver surgery	Cost-prohibitive, requires advanced robotic systems
Kim et al.,[8,10] Boehm et al.[22]	Flexible and Specialized Surgical Robots	Improves accessibility in complex anatomical sites, expands capabilities in head and neck surgery	Still in early development, high platform cost
Lajkó et al.,[23] Yazicioglu and Borat[24]	AI-Assisted Skill Assessment and Evolution of Surgical Robotics	AI evaluates surgical performance, outlines major advancements	Ethical concerns, lacks real-world implementation data
Shabir et al.,[9] Tonutti et al.[25]	Remote Tele-Mentoring and Role of Technology in MIS	Enhances surgeon training, identifies key technological advancements	Requires stable communication, limited AI ethics discussion
Haidegger et al.,[26] Palep et al.[32]	Future of AI in Surgery and Decision-Making	Predicts increased automation, AI enhances predictive analytics	Uncertainty in regulatory acceptance, requires extensive validation
Fong et al.[14]	Health-system impact of introducing RAS in common general surgery	Hospitals that adopted RAS saw a significant rise in MIS rates across patient subgroups vs hospitals that didn't adopt RAS.	Retrospective cohort; potential unmeasured confounders; cannot ascribe causality; cost/outcome deltas not fully addressed.
Dagnino and Kundrat[15]	State-of-the-art review of robot-assistive MIS; future directions (navigation, autonomy, data/AI)	Charts evolution of surgical robots and enabling tech; highlights trends toward greater automation, data-driven guidance, and integration with advanced imaging/AR.	Narrative review; no meta-analysis; limited quantitative benchmarking of AI/automation benefits.
Lee et al.[13]	Navigation-guided/robot-assisted spine surgery	Navigation/robotics improve pedicle-screw accuracy, reduce radiation exposure, and may shorten learning curves; outlines current systems and use-cases.	Evidence on long-term clinical outcomes and cost-effectiveness remains limited; heterogeneity across systems/studies.
Nagarkar et al.[12]	Center experience with RAMIE, India	Confirms feasibility and acceptable short-term outcomes for RAMIE in a tertiary center setting; adds data from an Indian cohort.	Single-center, likely retrospective, modest sample; no randomized comparator; generalizability and cost data limited.
Zaman et al.[30]	Systematic review/meta-analysis: robotic vs laparoscopic MIS for IB	Overall outcomes broadly comparable; some analyses show lower overall postoperative complications with robotics.	Heterogeneity in procedures and endpoints; limited randomized controlled trial (RCT) data; costs and learning-curve effects under-reported.
Lefor et al.[29]	VR simulator for robot-assisted minimally invasive liver surgery training (kinematics-aware)	First liver-procedure VR simulator providing standardized kinematic data; discriminated experts vs novices (time, movements, path length); supports objective skills assessment	Small validation cohort (n = 18); simulation fidelity constraints; access to real robot kinematics remains limited.
Scheese et al.[28]	Technical considerations and outcomes in RAMIE (review)	Describes RAMIE workflow, technical tips, and reported outcomes; positions robotics as an enabler of complex thoracic MIS.	Narrative review; few high-quality comparative trials; variability in technique/outcomes reporting.
Bunch et al.[27]	Spine: symbiosis of robotics with enabling tech (navigation, intra-op imaging, AR, computational planning/visualization)	Integration of robotics with imaging/navigation/AR is reshaping MIS workflows and precision; outlines current evidence and training/implementation considerations.	Review-level evidence; rapid tech evolution outpaces long-term outcomes/cost data; implementation barriers persist.

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of motion compensation techniques, particularly in robot-assisted surgeries. Adaptive algorithms have been implemented to refine robotic precision and ensure accurate movements, even in dynamic surgical environments. The introduction of AI-powered control systems has played a crucial role in mitigating human errors and optimizing performance in delicate procedures, such as neurosurgery, cardiac surgery, and orthopedic interventions.

Robotic systems have overcome the shortcoming of manual laparoscopy because they provide a greater level of dexterity and agility. Surgeries have also become more successful and quicker to heal, with robotic systems capable of making sutures and accurate cuts. Even more viable is that with the introduction of force feedback, haptic control and real-time imaging the surgeon can now be more precise and more assured of what they are doing. The other trend that has been dominant in robotic medicine is the advent of teleoperated surgical systems. Through this, highly skilled surgeons are able to carry out surgery in a different place despite geography. Telementoring and robot-assisted surgery have been most successful in emergency medicine, remote health stations, and military. Remote capability in real-time surgery has led to new possibilities to close the surgical talent gap and deliver surgical care to underserved populations.

Another revolutionary idea has been the notion of AI and inference aided by robots. AI models can also be used to optimize real-time decisions, predictive models and automated diagnostic routes. Machine learning algorithms have had a tremendous impact on expanding the proactive realm of healthcare management through processing medical images, identifying abnormalities, and forecasting the initial phases of the illness. Robotics and AI have also simplified the process of personalizing treatment plans, reduced misdiagnosis, and improved therapy outcomes. The issues that are most subject to debate in robotic healthcare concerns security and ethics.

There are problems with cybersecurity attacks, data protection, and decision accountability because an elevated level of autonomy has been found in robotic systems in robotic healthcare. To achieve patient safety and confidence in leveraging the application of robotic healthcare systems, tough legal conditions, high security standards and ethical conduct must be embraced to overcome such complications. To avoid the occurrence of sudden complications, researchers have promoted the introduction of XAI, decision transparency, and AI-based surgical procedure monitoring.

Despite these advantages, accessibility problems, the expensive use of robotic surgical systems, and the intensive training of medical personnel still exist. The implementation cost has remained a drawback to the large-scale implementation of robotic systems, particularly in healthcare infrastructural development. The next development must focus on cost-efficient bots, user-friendliness of systems, and overall improvement of the surgeon training program to reduce the existing imbalance in human-robot knowledge. The healthcare industry has transformed surgery, diagnosis, and patient care using robotics and AI technologies. All of this has been said about the capabilities of robotic medicine to revolutionize through advancements in precision, efficiency, and convenience. However, addressing the challenges related to ethical concerns, affordability, and security risks is essential to fully harness the benefits of these advanced technologies. Ongoing research and technological innovations will continue to shape the future of robot-assisted medicine, making it more adaptable, safe, and widely accessible to meet global healthcare needs.

MIS with the introduction of AI has resulted in significant advancements in accuracy, safety, and outcomes. In a series of studies, AI-controlled robotic systems have repeatedly demonstrated better results than traditional laparoscopy in complicated operations, though issues concerning cost, availability, and security have not been completely addressed.

Cross-Study Comparative Evidence

A number of studies have shown that robotic-assisted surgeries are better than the conventional laparoscopic surgeries. According to Xue et al.,[2] patients aged around 65 years who were provided with robotic systems during colorectal surgery experienced fewer complications and reduced the length of stay in the hospital. These results are consistent with the general review provided by Sheetz et al.[4] which emphasized the shortening of the recovery period and the reduction of postoperative complications in routine operations.

The degree of clinical benefit however depends on the complexity of cases. Although it is clear that robotic solutions may benefit technically demanding processes, such as esophagectomy[1] and neurovascular surgery,[8,10] the same is not true of regular surgery, where the costs can be more than the incremental benefits.

Measured Advantages and Costs

Stable short term clinical improvements are claimed:

Less Complications

The rates of complications of the surgery performed by robots are 20–30 times less than laparoscopy.[2,4]

Acquired Accuracy in Surgery

Greater dexterity and elimination of tremors enable extremely delicate suturing and dissection.

Haptic Feedback and Image

AI-enhanced image-sensing and force-sensing facilitate real-time decision-making.[3,6]

In addition to these benefits, there are also risks:

Because of High Cost

Robotic systems cost between 1.5–2 times per procedure more than laparoscopic systems.[17,21]

Cybersecurity Vulnerabilities

There are risks of command spoofing and data attacks in autonomous systems.[11]

Training Requirements
Robots platforms are difficult to learn and this limits their application in resource limited environments.

Evidence Gaps Identified
The literature indicates that there are a few areas that either have inconsistent evidence or lack evidence:

Absence of multicenter RCTs that compare robotic, laparoscopic and open MIS in different specialties.

Limited longitudinal outcome information, especially on recurrence rates, patient quality of life, and cost-benefit analysis over the long term (not just the perioperative period).

Low Global Representation
The vast majority of evidence is produced in high-income nations, and there is little information on the low- and middle-income areas where the issue of affordability is most severe.

Ethical and Legal Issues
Not many studies consider ethical accountability in the context of AI-driven decision-making and the regulatory frameworks that would govern clinical use.

Organized Future Research Schedule
To improve the safe, effective, and equitable implementation of AI-based robotic systems in surgery practice, the research of the future should address:

Clinical Validation
Complete large multicenter RCTs on a variety of surgical specialties to determine comparative effectiveness.

Affordability and Access
Build cost-effective robotic systems and test their viability in low-resource health care environments.

Cybersecurity and Liability
Internationalise the standards of cybersecurity and define the medico-legal liability of AI-induced mistakes.

Explainable AI
Focus on research in models of explainable machine learning to increase surgeon trust and patient safety.

Long-term Outcomes
To measure the long-term benefits of robotic MIS, use survival, recurrence, and patient reported outcomes.

Incorporation with Emerging Technologies
Test the effects of the combination of AR, soft robotics, and remote tele-mentoring on surgical training and outcomes.

Conclusion
Modern medicine has been revolutionized by progress in robot-assisted healthcare, leading to enhanced surgical accuracy, improved patient outcomes, and increased procedural effectiveness. The integration of AI has further boosted automation, flexibility, and instantaneous decision-making in minimally invasive techniques. Despite the substantial advantages of robotic systems, issues such as cost, availability, education, and ethical implications remain significant concerns. The expansion of robotic healthcare solutions depends on addressing these challenges. Future studies should focus on creating affordable, protected, and versatile robotic systems that augment surgical capabilities while safeguarding patient well-being and confidence in AI-powered medical technologies.

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