ACCSCIENCE PUBLISHING

INNOSC Theranostics and Pharmacological Sciences

REVIEW ARTICLE

Application of robotics in modern surgery and critical operations: Current status, challenges, and future directions

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Abstract

The field of modern surgery has undergone significant transformation with the integration of robotics, which offers unprecedented precision, reduced invasiveness, and improved surgical outcomes. Robotic-assisted surgery has gained popularity across various specialties, including neurosurgery, orthopedics, urology, and cardiac surgery, with systems such as the da Vinci Surgical System serving as a key example. These robotic platforms enhance surgical performance by providing greater control, three-dimensional visualization, and improved dexterity, which collectively reduce operating fatigue, minimize human error, and shorten patient recovery times. Despite these advancements, challenges remain, including high operational costs, the need for specialized training, and the limitations of robotic systems in handling complex or unforeseen situations. This review explores the current state of robotic applications in surgery, addressing both their potential and their limitations. It also discusses future developments, particularly the role of enhanced sensory feedback, machine learning, and artificial intelligence in advancing robotic surgery. While robotic technologies hold the promise of improving patient outcomes, reducing complications, and increasing accessibility, ethical, financial, and technological challenges still need to be addressed. As robotic technologies continue to evolve, they have the potential to reshape the landscape of essential procedures and surgeries.

Keywords: Machine learning; Medical science; Artificial intelligence; Robotic surgery

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Citation: Rahman MA, Bristi SA, Yesmin T, Islam MT. Application of robotics in modern surgery and critical operations: Current status, challenges, and future directions. *INNOSC Theranostics and Pharmacological Sciences*. 2025;8(3):12-20.
doi: 10.36922/itps.4664

Received: August 27, 2024

Revised: January 3, 2025

Accepted: January 16, 2025

Published online: February 6, 2025

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1. Introduction

Robots are autonomous machines capable of perceiving their surroundings, executing computations to make decisions, and performing various tasks based on given instructions.[1] The field of health and medical science is on the brink of a transformative

shift driven by robotic technologies. The development of artificial intelligence, miniaturization, and increased computing power are expanding the range of medical applications for robots. Over 34 years ago, an industrial robot and computed tomography navigation were first used successfully to insert a probe into a patient's brain to obtain a biopsy sample, marking the beginning of the field of medical robotics. This breakthrough was followed by the development of robots designed to perform certain urological treatments and total hip arthroplasty. However, these autonomous robots did not initially gain widespread acceptance among surgeons, leading to the development of later models that were designed to be controlled by doctors. Today, medical robots are recognized for their significant contributions to critical surgeries. More specifically, the use of robots, computers, and software to manipulate surgical tools with high precision through one or more incisions is one of the most prominent applications of medical robotics, particularly in fields such as orthopedic surgery, cardiac surgery, neurosurgery, and telesurgery.[1] Robotic manipulators in medicine are not limited to surgery; for example, a brain-machine interface (BMI) and a visual guiding system can provide shared control of a robotic arm in autonomous robotic grasping systems, as described by Dzedzickis *et al*.[2] A BMI is utilized to determine a user's intention to grasp or transfer an object, while visual assistance helps with tasks that involve low-level control, short-range motions, and the precise alignment of the robot's end-effector for grasping. Experiments have demonstrated that shared control of robotic movements leads to more precise, effective, and straightforward task completion compared to using BMI alone. In critical surgeries, achieving precision can be challenging; however, the ability to view the surgical area in three dimensions (3D) with high clarity allows surgeons to perform procedures with greater accuracy and control. It is estimated that the da Vinci system, which received the United States Food and Drug Administration (FDA) approval in 2000, has been used in more than six million surgical procedures worldwide, becoming the first robotic surgical system.[3] Robotic systems offer several advantages for both patients and surgeons, such as shorter recovery times, reduced blood loss, and smaller incisions. The long-term outcomes of robotic surgery are comparable to those of conventional surgery, although occasional malfunctions may occur. When compared to traditional laparoscopy, advanced laparoscopic techniques offer surgeons enhanced ergonomics and dexterity. However, the high cost of robotic systems and the need for specialized training for physicians and surgical teams remain significant drawbacks.[4] Robotic surgery reduces operator fatigue and human error, as it is less physically demanding than traditional surgery. Cardiac surgeries, for example, can last for many hours and are highly stressful for surgeons. Robotic systems allow surgeons to perform operations while seated comfortably, and unlike humans, robots do not experience fatigue. Their "hands" are typically rigid and steady, allowing them to maintain stability and precision during prolonged procedures. One of the main advantages of robotic surgery is the exceptional precision and accuracy it provides in catheter-based or surgical operations.[5] The primary aim of our review is to explore the application of robots in modern surgery and critical operations.

2. Application of robotics in critical surgeries

2.1. Robotic-assisted cardiac surgery

The most common method of myocardial protection in robotic-assisted surgery (RAS) for intracardiac repair involves placing an aortic cross-clamp and administering cardioplegia, similar to traditional open-heart surgery. However, installing an aortic cross-clamp may complicate surgery and perioperative outcomes in patients who have previously undergone cardiac surgery with mediastinal adhesions or those with severe aortic calcification.[3] Robotic assistance may offer additional benefits for tricuspid valve replacement or repair without the need for cross-clamping. The emergence of an atrioventricular block can help identify and promptly treat damage to the atrioventricular node caused by sutures placed through the septal portion of the tricuspid annulus, thus eliminating the need for pacemaker implantation.[4] Furthermore, the da Vinci Surgical System (Intuitive Surgical, United States of America) is one of the most advanced robotic systems used in cardiac surgery. This system consists of a console (from which the surgeon operates), a high-definition 3D vision system capable of magnifying images up to 10 times, and a side robotic cart with four robotic arms that the surgeon can control from the console. Three of the robotic arms are used for surgical instruments, while the fourth controls the camera. In laparoscopic or video-assisted thoracic surgery, the 3D endoscope provides better depth perception than conventional two-dimensional endoscopes. The surgeon at the console has complete control over the camera's orientation and positioning, which is not the case for the table-side surgical team. The da Vinci S® and da Vinci Si® systems, the second and third generations of this technology, offer easier arm movements and broader instrument reach compared to the first-generation model. The da Vinci Xi® is the fourth-generation model,[6] featuring additional enhancements such as a laser targeting system for easier robotic arm setup, thinner arms and instruments with longer reach, a movable endoscope that can be attached on any of the four robotic arms, and an overhead architecture/patient-

side cart with a boom mount for multi-quadrant surgery without requiring extensive repositioning.[7]

2.2. Robotic-assisted transplant surgery

The use of robotics in transplant surgery is rapidly rising, particularly in procedures requiring high accuracy, precision, and efficacy. Despite concerns about ischemic time, the complexity of the surgical procedures, and the level of training required, robotic transplants have yielded successful outcomes, particularly in obese patients.[8]

In the 1990s, substantial advancements in robotic surgery were made in the field of kidney transplant surgery. The development of accurate, minimally invasive robotic surgical systems, such as the da Vinci system (Intuitive Surgical, United States of America) has expanded the range of operations that can be performed, with kidney transplants showing particularly promising results. This method provides significant operational benefits, especially when the operating field is deep and limited, and delicate dissection and micro-suturing are required.[9] Several surgeons have attempted to perform robotic-assisted kidney transplantation in various ways, marking it as a new form of minimally invasive surgery. However, robotic surgery in organ donation is an advanced application of the technique, requiring a high level of expertise from any surgeon undertaking it.[10] Musquera Felip *et al.*[11] conducted a prospective analysis of the 1st 5 cases of robotic kidney transplantation through transvaginal access in 2021, utilizing an Alexis retractor. There were no procedural complications and conversion to an open approach was not required. Both the uretero-vesical anastomosis and vaginal closure were performed robotically. After the surgery, the kidney was placed extra-peritoneally. The median operation time was 220 min, with an average rewarming ischemia time of 53 min. Diuresis occurred immediately, and there were no intraoperative issues. The average hospitalization duration was nine days, with a mean serum creatinine level of 1.5 mg/dL at discharge. Research from the past 20 years indicates a growing use of robotic technology in kidney transplants, with encouraging and optimistic outcomes. Since the first case, various surgical procedures have been described. Initially, ureter implantation was performed using the conventional open technique, while robotic platforms were primarily utilized for vascular anastomosis and dissection.[12]

2.3. Robotic-assisted head and neck surgery

According to estimates, head and neck cancer is responsible for approximately 350,000 deaths and 65,000 new cases annually worldwide, making it the sixth most frequent type of cancer.[13] Prior research on robotic pediatric surgery has demonstrated its safety and low conversion rates to open surgery, where neonates weighing as little as 2.2 kg can undergo treatments using this surgical technique. There have been reports of adult patients who underwent head and neck surgery using robotic systems. Transoral robotic surgery (TORS) for ablative cancer treatment of the larynx and hypopharynx is gaining popularity.[13]

Head and neck squamous cell carcinomas account for approximately 4% of all malignant neoplasms in the United States. Transoral laser microsurgery has been employed as a minimally invasive technique in head and neck surgeries. Since the introduction of the first surgical robot in 1985, numerous medical specialties, including cardiac surgery, urology, general surgery, and gynecology, have found robotic systems to be valuable for enhancing surgical outcomes. TORS is a relatively new, minimally invasive approach in head and neck surgery, offering reduced patient morbidity and mortality.[9] TORS has been used for several years to treat oropharyngeal tumors in the early stages (T1-2) at selected tumor centers.[14] The technique provides advantages such as enhanced visualization, better tumor access, and reduced morbidity, all of which contribute to improved functional outcomes for patients.[10] A retrospective analysis of patients treated with TORS revealed positive outcomes in terms of survival rates, organ function, and quality of life. However, comparisons between TORS and conventional treatment procedures are infrequently addressed in clinical trials in this particular field. Several studies have found that patients who underwent TORS experience a good quality of life.[15] In a more recent study, comparing open transcervical surgery with TORS for patients with T1-4 hypopharyngeal tumors. The results showed no significant difference in overall survival after 5 years between the two patient groups. However, TORS-treated patients experienced improved post-operative swallowing function, shorter hospital stays, and faster recovery. In another retrospective study, patients treated with TORS had longer disease-free survival than those treated with transoral laser microsurgery.[16]

2.4. Robotic-assisted lung surgery

Robotic-assisted thoracic surgery (RATS) has become a significant focus in modern thoracic surgery. RATS is a minimally invasive technique that offers improved visibility, precise movements, and superior ergonomics for the surgeon.[17] RATS has been successfully used to treat early-stage non-small cell lung cancer.[18] RATS is considered one of the most advanced, minimally invasive surgical platforms for lung resection, offering several advantages over other minimally invasive surgical systems, such as enhanced visual haptics, seven degrees of freedom, and three-dimensional visualization. The use of robotic systems in lung resection has been advocated as a means

of improving surgical outcomes by reducing discomfort and accelerating recovery. A pooled analysis of 14 studies with 7,438 patients found that RATS is an effective and safe alternative to video-assisted thoracic surgery, resulting in lower 30-day mortality and conversion rates.[19] One type of robotic thoracic surgery is pure uniportal-RATS (U-RATS), which is performed through a single intercostal incision without rib spreading, using a robotic camera, dissecting tools, and staplers. U-RATS offers advantages such as easier management of potential intraoperative bleeding compared to multiport approaches, due to its quick undocking and the surgeon's required experience with the uniportal technique. U-RATS provides a potential solution for lung resections that is both comfortable for surgeons and promotes rapid recovery for patients. Additional benefits of RATS include 3D visualization and maneuverability. While current robotic systems are designed for multiport surgery (3 – 5 incisions),[20] a modification of the Davinci Xi® system has been developed specifically for the U-RATS technique. This adaptation allowed the execution of the world's first pure robotic cases in September 2021 in Spain. Since then, over 100 anatomic resections, including carinal resections, sleeve resections, multiple sleeve resections, and all segmentectomies, have been performed using this approach.[21]

2.5. Robotic-assisted thoracic esophagectomy

Esophageal cancer is ranked as the eighth most prevalent cancer globally and the sixth leading cause of cancer-related deaths by the World Health Organization. Minimally invasive esophagectomy (MIE) was first performed in the early 1990s, followed by the introduction of robotic-assisted procedures after the turn of the millennium. Over the past 15 years, the development of robotic-assisted MIE (RAMIE) has been facilitated by advancements in robotic platforms. While recent evidence suggests that RAMIE reduces post-operative morbidity and improves quality of life compared to open esophagectomy, no randomized trials have directly compared RAMIE with standard MIE. At our hospital, the hybrid robotic-assisted thoracoscopic procedure has demonstrated that there is a lower bar for patients to meet before they can undergo surgery. When comparing robotic-assisted esophagectomy to open esophagectomy, there were no statistically significant differences in post-operative complications or early oncological outcomes. Therefore, we believe that both methods are safe and effective.[9] The use of RAMIE for esophageal cancer has rapidly expanded globally, and this narrative review aims to clarify the current state and potential future directions of RAMIE. References were gathered from PubMed and Embase for papers published up until April 8, 2023, using search terms "robot," "robotic," or "robotic-assisted," "esophagectomy," and "esophageal cancer." In esophageal surgery, the robot can be utilized in various ways. Overall, complications from RAMIE are comparable to those from open esophagectomy and traditional thoracoscopic MIE, with some evidence suggesting lower rates of complications. RAMIE may help reduce pulmonary complications, according to several meta-analyses, although two randomized controlled studies showed similar incidences of these issues. Notably, RAMIE may facilitate the dissection of lymph nodes, particularly in the region of the left recurrent laryngeal nerve.[22] In addition, 10 cases of bilateral transcervical esophagectomy with robotic assistance performed at the National Cancer Center Hospital East in Japan between February and August of 2023 were examined. The study assessed the viability and effectiveness of the procedure, along with short-term surgical outcomes. The results demonstrated the safety and feasibility of robot-assisted bilateral transcervical esophagectomy for thoracic esophageal cancer. This procedure is expected to reduce the incidence of recurrent nerve palsy, a condition associated with mediastinoscopic esophagectomy and transcervical esophagectomy.[23] RAMIE has also been linked to significantly lower rates of wound infections (odds ratio [OR]: 0.20, 95% confidence interval [CI]: 0.07 – 0.57), atrial fibrillation (OR: 0.53, 95% CI: 0.29 – 0.98), pneumonia (OR: 0.39, 95% CI: 0.26 – 0.57), and overall pulmonary complications (OR: 0.38, 95% CI: 0.26 – 0.56). It also results in less blood loss (weighted mean difference [WMD]: −187.08 mL, 95% CI: −283.81 – −90.35), shorter hospital stays (WMD: −9.22 days, 95% CI: −14.39 – −4.06), but longer operative times (WMD: 69.45 min, 95% CI: 34.39–104.42). No other statistically significant differences in short-term oncological and surgical outcomes were observed. Comparisons between entirely robotic operations and open esophagectomy also yielded similar results. Overall, RAMIE is a safe and effective procedure that reduces blood loss, wound infections, cardiopulmonary morbidity, and hospital stays compared to open esophagectomy.[24]

2.6. Robotic-assisted neurosurgery

In the mid-1980s, surgeons began using the first robotic device for performing precise biopsies in neurosurgery. Initially, robotic surgery was used predominantly in neurosurgery but has since spread to other fields such as urology, gynecology, gastrointestinal surgery, and orthopedics. The use of robotic devices in neurosurgery offers the potential to improve surgical precision and enable more complex procedures for neurosurgeons. A retrospective review of 41 patients who underwent robotic-assisted frameless brain biopsies using the SurgiScope system demonstrated the safety, feasibility,

and excellent diagnostic yield (97.8%) of the technique.[25] Robotic applications in skull-based neurosurgery provide advantages such as better lighting and 3D visualization, replication of conventional gesture-based actions, and the capacity for precise movements in narrow operating corridors. However, the limitations of the robot include its enormous size, restricted angulation, high cost, and the lack of drilling components for fully robotic operations. Robotic endoscope holders have proven particularly useful in situations where a second surgeon or surgical assistant is not available.[26] Robotic assistance in neurosurgery is particularly beneficial for procedures that involve extremely small operating spaces. Examples of robotic use in neurosurgery include pedicle screw placement in spinal procedures, anatomical localization, the surgeon's hand stabilization, and anatomical access plan to deep brain targets.[27] Several robotic systems are commonly utilized in neurosurgery, including Neuromate, Pathfinder, NeuroArm, SpineAssist, and Renaissance. Although other surgical specialties may use robotic assistance more frequently, neurosurgery is well-suited for the integration of robotic technology due to its technical and microsurgical procedures, as well as its history of invention in stereotaxy.[28] Since 2019, our hospital has performed over 100 robot-assisted stereoelectroencephalography and deep brain stimulation depth electrode implantations. Residents and fellows are actively involved in the surgeries and participate in all aspects of surgical planning and execution. It is emphasized that didactic seminars conducted by experienced faculty members are essential learning resources prior to gaining practical experience in the operating room. Survey findings suggest that residents receive more intraoperative training than formal training sessions, while trainees gain more knowledge from educational cadaveric simulation sessions.[29]

2.7. Robotic-assisted trauma surgery

The stabilization of severely injured patients through teleoperative robotic assistance or autonomous robotic surgery is gaining popularity, particularly among military personnel. The trauma pod, a semi-automated telerobotic surgical device, and its proof of concept were introduced by Garcia *et al.*[10] The use of teleoperation to perform bowel anastomosis and shunt insertion in major vessels, along with the ability to facilitate intraoperative computed tomography scanning, was demonstrated on a mannequin patient. This robot's autonomous robotic arms could potentially function as circulation and scrub nurses, which is a significant advantage. Although this prototype is still in its early stages, it highlights the progress yet to be made before surgical robots can be used in clinical settings. In trauma surgery, robots are also useful for navigating to entry points and locking distal bolts.[30] In clinical trauma orthopedics, surgical robots are categorized into three categories: TiRobot, electromagnetic navigation surgical robots, and miniature medical robots developed by Beijing Jishuitan Hospital. Most trials have shown that the robotic group outperformed traditional methods in terms of blood loss, fluoroscopy time, and fluoroscopy frequency. The benefits of robot-assisted surgery are evident: it is more accurate, stable, and reduces radiation exposure during procedures.[31] In the context of open and minimally invasive spinal fusion, robotic assistance has been demonstrated to improve the precision of instrumentation placement. These improvements are achieved without increasing hospital stays, blood loss, or operating time. Nevertheless, most research has focused on the degenerative population, and the effectiveness of robotic assistance in treating spinal injuries remains unknown. A study involving 42 patients (mean age 61.3 ± 17.1 years; 47% female) who underwent robot-assisted spinal surgery was conducted. The patients were stratified based on the number of operation levels: 2 (n = 10), 3 – 4 (n = 11), 5 – 6 (n = 13), or >6 (n = 8). This initial experience suggests that robotic assistance can be safely used in the population with spine trauma. Further studies with larger patient groups are needed to identify which traumatic conditions are most suitable for robotic support.[32]

2.8. Robotic-assisted obstetric and gynecologic surgery

The invention of robotic surgery has enabled gynecologic surgeons to provide laparoscopic options to a much larger percentage of their patient population. Surgeons with advanced laparoscopic skills can improve operative efficiency for numerous procedures involved in benign gynecologic treatments, particularly after performing 50 or more cases.[33] Robotic-assisted laparoscopic procedures in gynecology include lymph node dissections, sacrocolpopexies, benign hysterectomy, myomectomy, tubal reanastomoses, and radical hysterectomy. Numerous recent studies feature case studies of various robotic procedures. Comparative retrospective and prospective studies have shown that this specific form of surgery is feasible. While robot-assisted gynecologic surgery is frequently linked to longer operating room times, it generally results in similar clinical outcomes, reduced blood loss, and shorter hospital stays, although individual studies vary. As more gynecologic surgeons receive training and as patients increasingly seek minimally invasive surgical options, robot-assisted gynecologic surgery is expected to continue advancing.[18] Robotic-assisted laparoscopic hysterectomy is most commonly used in gynecological oncology, particularly for endometrial cancer, though it is

also occasionally employed for restaging early ovarian and cervical cancer.[34] Compared to traditional keyhole and open abdominal surgery, the advantages of 3D viewing include enhanced depth perception, reduced tremor, improved precision, better tissue discrimination, a shorter learning curve, and increased surgeon comfort. When compared to traditional keyhole surgery, robotic-assisted keyhole surgery reduces blood loss and intra- or post-operative complications, enhances surgical performance without extending operating time, and decreases the need for abdominal surgery.[35] One study found that the introduction of robots in the United Kingdom led to a decrease in the number of open radical hysterectomies. A recent meta-analysis reviewing nine studies demonstrated widespread acceptance of robots for cervical cancer surgery, not only for hysterectomy but also for trachelectomy.[36]

2.9. Robotic-assisted pediatric surgery

For the past 20 years, children have been undergoing RAS, a novel technology with various potential clinical benefits, such as decreased post-operative discomfort, shorter hospital stays, and better cosmetic outcomes. As the demand for this cutting-edge technology in pediatric surgery continues to grow, pediatric anesthesiologists will be required to provide anesthetic care for patients undergoing procedures with unique intraoperative requirements and potential complications.[37] Robots have been used to assist in a huge number of pediatric surgical procedures, with success rates comparable to those of traditional laparoscopy.[19] RAS is safe and effective for children, and its application in pediatric surgical specialties has been steadily increasing. It is anticipated that its current limitations will be addressed in the future through further evaluation of robotic systems and surgical expertise. For instance, some adult-focused studies and recent pediatric case reports indicate that 3 mm devices represent a promising technological advancement in minimally invasive pediatric surgery.[38] Over the past few years, laparoscopic techniques have been proven beneficial and safe for both adult and pediatric populations. As

Table 1. Applications of robotics in modern surgery and critical operations

Aspect	Present status	Expectations	Challenges
Robotic systems	Robotic-assisted surgery (e.g., da Vinci surgical system) is widely used in minimally invasive procedures	Development of more specialized robots for specific organs, procedures, or tasks	High initial costs of robotic systems
Applications	Commonly used in urology, gynecology, cardiac surgery, and orthopedics	Expansion into neurosurgery, pediatric surgery, and other complex areas	Limited access to advanced robotic systems in low-resource settings
Precision and minimally invasive surgery	Robots provide enhanced precision, stability, and range of motions in surgery	Further precision improvements to reduce human error and enhance outcomes in complex procedures	Potential over-reliance on technology, reducing human surgical skills in the long term
Tele-surgery	Tele-surgery is becoming more viable with advancements in 5G and communication technologies	Remote surgery capabilities, allowing experts to operate from afar	Reliance on high-speed internet and the risk of delays during critical procedures
Training and simulation	Robotic surgery training systems exist but are not universally accessible	Advanced simulators for safer, risk-free training without the need for patient involvement	Unequal access to training, particularly in developing countries
Patient recovery and outcomes	Robotic surgery has been shown to reduce blood loss, pain, and recovery time	Continued improvement in patient outcomes through even less invasive techniques	Uncertainty about long-term benefits and potential complications
Integration with AI	AI and machine learning are integrated into some robotic systems to provide decision support	Full AI integration to assist surgeons in diagnosis, planning, and real-time decision-making	Ethical concerns and the need for regulations regarding AI involvement in critical decisions
Cost-effectiveness	High upfront cost and maintenance requirements of robotic systems	Reduced costs over time through widespread adoption, improving cost-effectiveness	High initial costs may limit widespread adoption, especially in public healthcare systems
Safety and error reduction	Improved safety through precision, but risks remain due to robot malfunctions or user errors	Reduction of human error and more reliable robotic systems	Risk of malfunctions or system failures during critical surgeries
Personalized medicine	Robots enable precision medicine by adapting to each patient's unique anatomy	Tailoring robotic procedures to individual patient's needs, reducing risks, and improving recovery	Need for greater customization of robotic systems for different body types and medical conditions

Abbreviations: AI: Artificial intelligence; 5G: The fifth generation of cellular network technology.

previously demonstrated, laparoscopy offers shorter hospital stays, smaller surgical scars, and faster recovery. In some cases, it has even replaced open surgery as the preferred approach. However, more complex procedures, particularly intracorporeal anastomosis or extensive reconstruction, have hindered its widespread adoption.[39] Studies comparing robotic surgery to traditional open or laparoscopic procedures found that robotic surgery resulted in shorter hospital stays and produced comparable outcomes in the adult population.[40] The first robotic surgical system, da Vinci (Intuitive Surgical, United States of America), received FDA approval in 2000. In a more recent study, reported that 20 out of the 24 patients who underwent robot-assisted interventions were successfully treated using the da Vinci. Procedures included eight antegrade continence enemas, six bladder neck repair surgeries, and 16 appendicovesicostomies.[35] These findings highlight that the robot provides functional outcomes similar to those of open or laparoscopic surgeries, while also offering the benefits inherent in minimally invasive surgery. Although robotic surgery is reliable and effective for complex procedures in children, its advantages must be weighed against the increased costs and longer operating times associated with this technology.[19] Notably, challenges remain, such as the mismatch between large instruments and the small thorax, the higher risk of skin scarring compared to a thoracoscopic technique, and the high cost of robotic surgery for cardiothoracic disorders. Robotic cardiothoracic surgery in children remains challenging, with only a small number of patients being suitable candidates, and the indications for its use must be closely monitored.[41] Applications of robotic technology in modern surgery and critical operation are summarized in Table 1.

3. Conclusion and future perspectives

Robotic technology has overcome many of the challenges associated with conventional endoscopic surgery, ushering in a new era in medical science that has contributed to a reduction in mortality rates. However, there are concerns that the widespread adoption of advanced robotic technology could lead to job displacement for doctors and other healthcare professionals.

Acknowledgments

None.

Funding

None.

Conflict of interest

The authors declare that they have no competing interests.

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Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Not applicable.

References

1. Thai MT, Phan PT, Hoang TT, Wong S, Lovell NH, Do TN. Advanced intelligent systems for surgical robotics. *Adv Intell Syst*. 2020;2:1900138.

   doi: 10.1002/aisy.201900138

2. Dzedzickis A, Subačiūtė-Žemaitienė J, Šutinys E, Samukaitė-Bubnienė U, Bučinskas V. Advanced applications of industrial robotics: New trends and possibilities. *Appl Sci*. 2021;12:135.

   doi: 10.3390/app12010135

3. Macmanus Q, Okies JE, Phillips SJ, Starr A. Surgical considerations in patients undergoing repeat median sternotomy. *J Thorac Cardiovasc Surg*. 1975;69:138-143.

   doi: 10.1016/S0022-5223(19)41621-8

4. Güllü AU, Şenay S, Ersin E, *et al*. Robotic-assisted cardiac surgery without aortic cross-clamping: A safe alternative approach. J Cardiac Surg. 2021;36:165-1681.

   doi: 10.1111/jocs.15160

5. Koulaouzidis G, Charisopoulou D, Bomba P, *et al*. Robotic-assisted solutions for invasive cardiology, cardiac surgery and routine on-ward tasks: A narrative review. *J Cardiovasc Dev Dis*. 2023;10:399.

   doi: 10.3390/jcdd10090399

6. Ferguson JM, Pitt B, Kuntz A, *et al*. Comparing the accuracy of the da Vinci Xi and da Vinci Si for image guidance and automation. *Int J Med Robot*. 2020;16:1-10.

   doi: 10.1002/rcs.2149

7. Ojima T, Nakamura M, Hayata K, Kitadani J, Takeuchi A, Yamaue H. Comparison of short-term surgical outcomes using da Vinci S, Si and Xi surgical system for robotic gastric cancer surgery. *Sci Rep*. 2021;11:11063.

doi: 10.1038/s41598-021-90741-2

8. Khan AS, Scherer M, Panni R, *et al*. Total robotic liver transplant: The final frontier of minimally invasive surgery. *Am J Transplant*. 2024;24:1467-172.

   doi: 10.1016/j.ajt.2024.03.030

9. Carvalho TC, Borges AKDM, Koifman RJ, De Silva IF. Time trends in colorectal cancer incidence in four regions of Latin America: 1983-2012. *Cad Saude Publica*. 2021;37:e00175720.

   doi: 10.1590/0102-311X00175720

10. Garcia P, Rosen J, Kapoor C, *et al*. Trauma pod: A semi-automated telerobotic surgical system. *Int J Med Robot*. 2009;5:136-146.

    doi: 10.1002/rcs.238

11. Musquera Felip M, Ajami Fardoun T, Peri Cusi L, Alcaraz Asensio A. Technique description and outcomes of robotic transvaginal-assisted living donor kidney transplantation. *Urol Int*. 2021;105:148-154.

    doi: 10.1159/000511756.

12. Di Pangrazio M, Pinto F, Martinino A, Toti F, Pozza G, Giovinazzo F. Robotic surgical techniques in transplantation: A comprehensive review. *Transplantology.* 2024;5:72-84.

    doi: 10.3390/transplantology5020008

13. Whiteman E, Rehman U, Hussien M, Sarwar MS, Harsten R, Brennan PA. The implementation of robotic systems in paediatric craniofacial and head and neck surgery: A narrative review of the literature. *Br J Oral Maxillofac Surg*. 2024.

    doi: 10.1016/j.bjoms.2024.11.011

14. Weinstein GS, O'Malley BW Jr., Magnuson JS, *et al*. Transoral robotic surgery: A multicenter study to assess feasibility, safety, and surgical margins. *Laryngoscope*. 2012;122:1701-1707.

    doi: 10.1002/lary.23294.

15. Dziegielewski PT, Teknos TN, Durmus K, *et al.* Transoral robotic surgery for oropharyngeal cancer: Long-term quality of life and functional outcomes. *JAMA Otolaryngol Head Neck Surg*. 2013;139:1099-1108.

    doi: 10.1001/jamaoto.2013.2747

16. Hussain T, Lang S, Haßkamp P, Holtmann L, Höing B, Mattheis S. The Flex robotic system compared to transoral laser microsurgery for the resection of supraglottic carcinomas: First results and preliminary oncologic outcomes. *Eur Arch Otorhino-Laryngol*. 2020;277:917-924.

    doi: 10.1007/s00405-019-05767-0

17. Mattioni G, Palleschi A, Mendogni P, Tosi D. Approaches and outcomes of robotic-assisted thoracic surgery (RATS) for lung cancer: A narrative review. *J Robotic Surg*. 2023;17:797-809.

    doi: 10.1007/s11701-022-01512-8

18. Visco AG, Advincula AP. Robotic gynecologic surgery. *Obstetr Gynecol*. 2008;112:1369-1384.

    doi: 10.1097/AOG.0b013e31818f3c17

19. Mei H, Tang S. Robotic-assisted surgery in the pediatric surgeons' world: Current situation and future prospectives. *Front Pediatr*. 2023;11:1120831.

    doi: 10.3389/fped.2023.1120831

20. Gonzalez-Rivas D, Bosinceanu M, Motas N, Manolache V. Uniportal robotic-assisted thoracic surgery for lung resections. *Eur J Cardiothorac Surg*. 2022;62:ezac410.

    doi: 10.1093/ejcts/ezac410

21. Gonzalez-Rivas D, Manolache V, Bosinceanu ML, *et al*. Uniportal pure robotic-assisted thoracic surgery-technical aspects, tips and tricks. *Ann Transl Med*. 2022;11:362.

    doi: 10.21037/atm-22-1866

22. Watanabe M, Kuriyama K, Terayama M, Okamura A, Kanamori J, Imamura Y. Robotic-assisted esophagectomy: Current situation and future perspectives. *Ann Thorac Cardiovasc Surg*. 2023;29:168-176.

23. Fujita T, Sato K, Fujiwara N, *et al*. Robot-assisted transcervical esophagectomy with a bilateral cervical approach for thoracic esophagectomy. *Surg Endosc*. 2024;38:1617-1625.

    doi: 10.1007/s00464-024-10692-3

24. Esagian SM, Ziogas IA, Skarentzos K, *et al*. Robot-assisted minimally invasive esophagectomy versus open esophagectomy for esophageal cancer: A systematic review and meta-analysis. *Cancers* (*Basel*). 2022;14:3177.

    doi: 10.3390/cancers14133177

25. Smith JA, Jivraj J, Wong R, Yang V. 30 years of neurosurgical robots: Review and trends for manipulators and associated navigational systems. *Ann Biomed Eng*. 2016;44:836-846.

    doi: 10.1007/s10439-015-1475-4

26. Pangal DJ, Cote DJ, Ruzevick J, *et al*. Robotic and robot-assisted skull base neurosurgery: Systematic review of current applications and future directions. *Neurosurg Focus*. 2022;52:E15.

    doi: 10.3171/2021.10.FOCUS21505

27. Elswick CM, Strong MJ, Joseph JR, Saadeh Y, Oppenlander M, Park P. Robotic-assisted spinal surgery: Current generation instrumentation and new applications. *Neurosurg Clin N Am*. 2019;31:103-110.

    doi: 10.1016/j.nec.2019.08.012

28. Singh R, Wang K, Qureshi MB, Rangel IC, *et al*. Robotics in neurosurgery: Current prevalence and future directions. *Surg Neurol Int*. 2022;3:373.

    doi: 10.25259/SNI_522_2022

29. Mallela AN, Beiriger J, Gersey ZC, *et al*. Targeting the future: Developing a training curriculum for robotic assisted

neurosurgery. *World Neurosurg*. 2022;167:e770-e777.

doi: 10.1016/j.wneu.2022.08.076

30. Oszwald M, Westphal R, Klepzig D, *et al*. Robotized access to the medullary cavity for intramedullary nailing of the femur. *Technol Health Care*. 2010;18:173-180.

doi: 10.3233/THC-2010-0580

31. Xu D, Lou W, Li M, Xiao J, Wu H, Chen J. Current status of robot-assisted surgery in the clinical application of trauma orthopedics in China: A systematic review. *Health Sci Rep*. 2022;5:e930.

doi: 10.1002/hsr2.93 0

32. Diaz-Aguilar LD, Brown NJ, Bui N, *et al*. The use of robot-assisted surgery for the unstable traumatic spine: A retrospective cohort study. *North Am Spine Soc J (NASSJ)*. 2023;15:100234.

doi: 10.1016/j.xnsj.2023.100234

33. Lenihan JP Jr., Kovanda C, Seshadri-Kreaden U. What is the learning curve for robotic assisted gynecologic surgery? *J Minim Invasive Gynecol*. 2008;15:589-594.

doi: 10.1016/j.jmig.2008.06.015

34. Moss EL, Morgan G, Martin AP, Sarhanis P, Ind T. Surgical trends, outcomes and disparities in minimal invasive surgery for patients with endometrial cancer in England: A retrospective cohort study. *BMJ Open*. 2020;10:e036222.

doi: 10.1136/bmjopen-2019-036222

35. Nobbenhuis MA, Gul N, Barton-Smith P, *et al*. Robotic surgery in gynaecology: Scientific impact paper No. 71 (July 2022). *BJOG*. 2023;130:e1-e8.

doi: 10.1111/1471-0528.17242

36. Ind TE, Marshall C, Kasius J, Butler J, Barton D, Nobbenhuis M. Introducing robotic radical hysterectomy for stage 1bi cervical cancer-a prospective evaluation of clinical and economic outcomes in a single UK institution. *Int J Med Robot*. 2019;15:e1970.

doi: 10.1002/rcs.1970

37. Wakimoto M, Michalsky M, Nafiu O, Tobias J. Anesthetic implications of robotic-assisted surgery in pediatric patients. *Robot Surg*. 2021;8:9-19.

doi: 10.2147/RSRR.S308185

38. Krebs TF, Schnorr I, Heye P, Häcker FM. Robotically assisted surgery in children-a perspective. *Children* (*Basel*). 2022;9:839.

doi: 10.3390/children9060839

39. Rassweiler JJ, Teber D. Advances in laparoscopic surgery in urology. *Nat Rev Urol*. 2016;13:387-399.

doi: 10.1038/nrurol.2016.70

40. Boscarelli A, Giglione E, Caputo MR, *et al*. Robotic-assisted surgery in pediatrics: What is evidence-based?-A literature review. *Transl Pediatr*. 2023;12:271.

doi: 10.21037/tp-22-338

41. Ferrero PA, Blanc T, Binet A. The potential and the limitations of esophageal robotic surgery in children. *Eur J Pediatr Surg*. 2022;32:170-176.

doi: 10.1055/s-0040-1721770