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Medical robots application in surgery

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Abstract

Robotic surgery as a field of application represents a major technological advancement within modern medical practice. Such technology offers surgeons and patients increased precision, flexibility, and control in intricate procedures, thus revolutionizing the surgical sector. This chapter will discuss the concept of robotics within a surgical setting, explain how robotic systems have transformed various surgical system, and highlight the potential or realized impact of robotic surgery on patient outcomes. The procedure like laparoscopic and robotic assisted are accepted due to a great benefit like, reduction of blood loss, fast recovery time and low rate of patient discomfort. Medication enables surgeons to perform minute and intricate operations while delivering a level of precision not achievable through traditional methods. The development and application of robotic systems in surgery are assessed from the rudimentary model to the contemporary Da Vinci Surgical System, and these products' design, function, and scope are further predicted. It also outlines the significance of robotics in surgery concerning improving patients' clinical outcomes and the prominent challenges experienced in adopting the technology. Finally, this paper discusses the future of robotics in surgical applications regarding expanding the limits of medical practice. This chapter defines the future of surgery and how robotics will shape medical practice.

Keywords: Robotic surgery, technological advancement, modern medical practice, precision, flexibility, control, minimally invasive procedures, patient outcomes, da vinci surgical system, clinical outcomes, surgical applications, medical practice, innovation in surgery

Introduction

Medical robots have revolutionized the surgical field by enhancing precision, efficiency, and overall patient care. Their applications range from robotic-assisted surgeries to various supporting roles that facilitate complex medical procedures.

The integration of robotics into the medical field has significantly altered surgical practices, introducing an era of advanced precision and efficiency (Tanwar, B. S. S. *Et al*., 2022) [21]. Medical robots, such as the da Vinci Surgical System, allow surgeons to perform intricate procedures with improved control and visualization. (https://www.mayoclinic.org/tests-procedures/robotic-surgery/about/pac-20394974).

Robotic-assisted surgeries offer numerous benefits, including enhanced precision during operations. The robotic systems can hold surgical instruments steady and align them perfectly, which is particularly beneficial in delicate procedures such as spinal and laparoscopic surgeries. (https://www.brainlab.com/journal/types-of-medical-robots-in-use-today-and-in-the-future/). Additionally, these systems minimize the physical strain on surgeons, allowing for more complex maneuvers during challenging surgical approaches.

Surgical applications of medical robots are diverse and have expanded over the years. They include robotic assistance in various fields such as general surgery, urology, gynecology, and orthopaedics. Each application leverages robotic technology to perform procedures that were once limited to traditional open surgeries, providing patients with a safer and less invasive alternative (https://my.clevelandclinic.org/health/treatments/22178-robotic-surgery).

The advantage of robotics extends to improved surgical outcomes, as studies show a success rate of robotic surgery between 94% to 100%, depending on various factors (https://my.clevelandclinic.org/health/treatments/22178-robotic-surgery). These high success rates are attributed to the advanced technology that enhances the surgeon's ability to navigate complex anatomy with greater accuracy and speed. The robotic surgery have explore the advantage in artificial intelligence and machine learning which result to autonomous capabilities and transforming surgical practices, for the future robotic surgery count for promising potential with more innovations aimed to increasing autonomous and efficiency in medical procedures.

History and development

The word “robot” was first introduced by Karel Capek, in his play Rossom’s Universal Robots (R. U. R.), published in 1921 (Pugin F *et al*. 2011) [18]. Isaac Asimov in his science fiction novel I, Robot (1954), first used the word “robot” and proposed three laws of Robotics (C. Chellapandi *et al*. 2023) [10]. Telesurgery or remote surgery came into existence during 1970s when National Aeronautics and Space Administration (NASA) and Defense Advanced Research Projects Agency (DARPA) developed the mechanisms and technology to carry out surgical procedure from a remote site like space station or war fields but these remained as distant possibilities. However, robotic telesurgery along with relevant telecommunication technology and instruments of ward had another significant step in the year 2001, the Lindberg Operation, French physician Jacques Marescaux helped Canadian-born surgeon Michel Gagner to perform a cholecystectomy remotely. Furthermore due to time delay issue there was lack of immediacy limited utilization of telesurgery.

Another goal of robotic surgery was the removal of undesired motion. In 1985, the first surgical robot (PUMA 560) was employed in stereotaxic operation (Pugin F *et al*. 2011) [18]. The robot could perform a brain biopsy by inserting a needle under computed tomography guidance, which was previously prone to inaccuracies due to hand tremor while inserting the needle. A PROBOT was developed 3 years later at Imperial College London for transurethral prostate resection; here too, the mechanical nature of the task allowed for an easy exploitation of robotics advantages. The American company Integrated Surgical Systems, Inc. (ISS) and IBM developed ROBODOC that also in 1992 for the first time successfully assisted human surgeons in preparing a femur cavity for hip endoprosthesis replacement surgery; it performed more accurately and faster than human surgeons. By the late 90s, engineers had developed three laparoscopic-technology-merged surgical robotic systems. They were developed by three engineers and their associated companies who are da Vinci Surgical Systems of California-based Intuitive Surgical, Inc.; AESOP and Zeus Robotic Surgical System of Computer Motion, Inc., a California company. Their AESOP system was the first to be approved for endoscopic surgical procedure by the Food and Drug Administration (FDA). The Zeus system carried out many robotic surgeries including laparoscopic fallopian tube anastomosis and cardiac revascularization (Ewing D *et al*. 2004).

The surgical robotic technology dates back to the 1990s, with NASA developing advanced robotic systems for space exploration during that decade. These systems were later researched for surgical applications in collaboration with medical researchers. Other key developments in the 2000s included the "da Vinci Surgical System" (2000) and the "MAKO Surgical System (2005)," with DARPA supporting medical robotics innovations. In the 2010s, systems like the "Renaissance Guidance System" (2010) and "Medtronic Mazor X" (2011) were introduced, followed by "Hugo" and "Versius" around 2015. Today, NASA continues to invest in technological advancements by collaborating with medical researchers, and AI-driven techniques have further proliferated robotics for surgical applications across various medical disciplines.

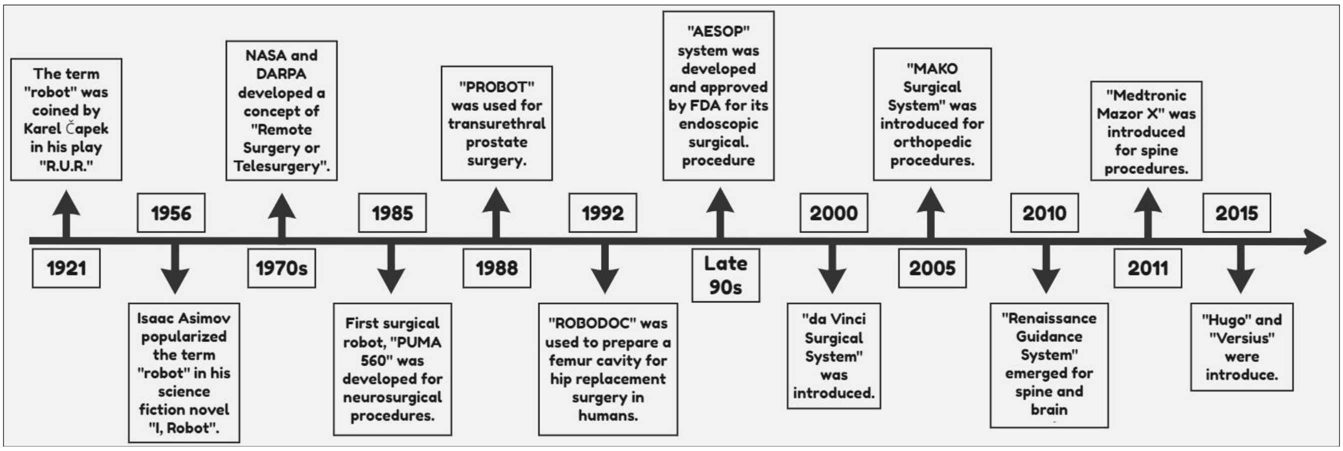

Fig 1: History and Development of Medical Robots in Surgery.

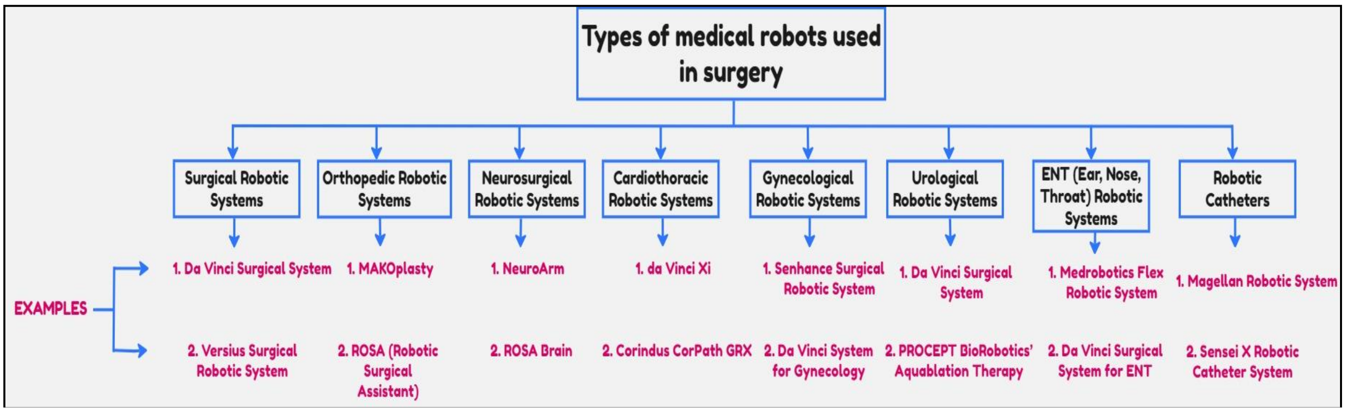

Fig 2: Types of Surgical Robot with two examples

Types of surgical robots

Surgical procedures have been drastically changed by medical robots with their ability to provide high levels of precision, control, and less invasive options. Following are the Medical Robots Used in Surgery

A. Surgical Robotic System

- **Da Vinci Surgical System:** The da Vinci Surgical System is one of the most widely used robotic surgical platforms. It allows surgeons to perform complex minimally invasive surgical procedures with precision. The system includes features like interactivity through robotic arms and enhanced 3D visualization, which together improve surgical accuracy
- (https://www.uchealth.com/services/robotic-surgery/patient-information/davinci-surgical-system/)
- **Versius Surgical Robotic System:** The design of the system provides robotic arm versatility and ease of use, intended for various laparoscopic operations.

B. Orthopedic Robotic Systems

- **MAKOplasty:** This state-of-the-art robotic-assisted system revolutionizes partial or total hip and knee replacements, offering extreme precision to ensure accurate results by adjusting for body muscular, soft tissue alignment while providing patient-specific solutions with few downsides.
- **ROSA (Robotic Surgical Assistant):** Generally applied for knee and hip replacements, it also involves the provision of live information along with a visual guide to improve precision in surgery.

C. Neurosurgical Robotic Systems

- **NeuroArm:** This system is helpful in neurosurgery as it helps in performing precise and delicate operations within the brain or spinal cord. By allowing real-time *in vivo* imaging and micromanipulation of neural tissue, it takes the capacity and precision of robotics and adds the decision-making of the human mind.
- **ROSA Brain:** A robotic surgical machine designed for neurosurgery, specifically for electrode introduction during deep brain stimulation and other cranial surgeries. The system involves a robotic arm and console that makes less invasive surgeries possible with small instruments. ROSA is a stereotactic robot system where a computer coordinates ROSA's movements, and the neurosurgeon controls its robotic arm. It is not a substitute for the surgeon.

D. Cardiothoracic Robotic Systems

- **Da Vinci Xi:** The Xi model is built for more complicated tasks like heart and lung surgeries by adding longer, thinner arms to the traditional da Vinci system. It allows for finer manipulation in tighter spots of the chest.
- **Corindus CorPath GRX:** Mainly for peripheral and coronary use, this system makes it possible to steer the placement of catheters and stents with high accuracy, reducing radiation exposure for both patients and medical staff.

E. Gynecological Robotic Systems

- **Senhance Surgical Robotic System:** Used for laparoscopic gynecological procedures, the system provides haptic feedback, giving the surgeon a sense of tissue resistance. It performs minimally invasive surgery for applications like hysterectomy and myomectomy.
- **Da Vinci System for Gynecology:** Used for specific women’s health procedures, such as cancers of the uterus, endometrium, and cervix. Advantages for patients may include less pain, less blood loss, and a shorter hospital stay with reduced recovery time.

F. Urological Robotic Systems

- **Da Vinci Surgical System:** Commonly used in urological surgeries, especially prostatectomy, this system allows precise and fine manipulation through robotic instruments, resulting in better outcomes with shorter recovery periods.
- **PROCEPT BioRobotics’ Aquablation Therapy:** For treating benign prostatic hyperplasia (BPH), this system uses robotics and real-time imaging to minimize complications from major surgery.

G. ENT (Ear, Nose, Throat) Robotic Systems

- **Medrobotics Flex Robotic System:** Enables surgeons to reach difficult areas within the throat that are hard to access by traditional surgeries for head and neck cases. The flexible design allows for complex operations in a less invasive manner.
- **Da Vinci Surgical System for ENT:** Additionally, used in transoral surgeries like throat cancer, offering precision and minimally invasive options.

H. Robotic Catheters

- **Magellan Robotic System:** Used in several endovascular procedures, this robotic system allows remote-controlled navigation through blood vessels, reducing catheter and device positioning risks during complex vascular processes.
- **Sensei X Robotic Catheter System:** Employed mostly for electrophysiology in treating heart arrhythmias, this system improves catheter stability and control in ablation procedures.

Applications

Surgery is one of the many applications of robots. Medical robots allow surgeons to specify the precise arrangement of the surgical tools. This means even operations that cannot be performed in the traditional operations can be managed by the robots. The motive of using the robots in the surgical operations is the better outcomes. For example, in the minimally invasive surgery, the robot is operated by the surgeon sitting on a computer that is at a distance from the patient. Hence, the surgeon is at a minimal risk of being exposed to the radiation, as the surgeon may be during the traditional open surgeries. Another surgery application is correction of the cervical abnormalities. This type of spinal surgery is very demanding for the surgeons and even a small failure can lead to paralysis. The use of robots significantly reduces the chance of human errors. The robots have also been used in other surgery applications such as correcting joint deformities, fracture reduction, and body stereotactic surgery (W Zhang, H Li, *Et al*., 2021) [24].

This paper intends to show that the progress in robot technology has helped the medical field. In the last decade, the medical field is becoming more pervasive in using robots. As a result, considerable funds from the government are being invested in medical robotics. The result of this research is obviously influential in both the medical and robotic fields.

However, this paper focuses on one of these applications: Use of robots in different surgery applications. In particular, minimally invasive surgery (MIS) and microscopic manipulation are investigated. The main objective of our work is to propose the best method to navigate a robotic arm to a specified point in the presence of obstacles. Our experience is unique in that our proposed approach is applicable to free-floating manipulation that is characterized by the following: An obstacle exists near the robot, and the robot has limited movements (M Kyrarini, *Et al*., 2021) [15].

Colorectal surgery: the subspecialty that paved the way

The cost of robotic surgery has always been an element of strong criticism used against its adoption in multiple surgical subspecialties, including the pioneer, colorectal surgery. However, even in those well-conducted studies, the benefits of robotic surgery have been noted without a doubt, such as better outcomes in left colectomies, particularly when approaching the rectum when compared to even the most sophisticated 3-D laparoscopic systems. As early as 2013, several manuscripts in the field of robotic colorectal resections were analyzed and the conclusions suggested that robotic surgery would continue to advance and overcome its own weaknesses, with improved outcomes comparable to those of conventional laparoscopy. American Journal of Robotic Surgery.2014;

Hepatobiliary and pancreatic surgery- nothing is impossible

The hepatobiliary and pancreatic subspecialty is considered one of, if not the absolute most, complex and technically challenging across general surgery. Another way to describe this: most surgeons uphold that a pancreatico-duodenectomy is the most difficult operation in the world, second perhaps to a liver transplant (Avgousti S, *et al*., 2016) [9]. What was impossible apparently a few years ago has now been achieved with hard work and the process of trial and error, by which many experts advanced the field into the realm of the minimally invasive and transformed those operations which, conventionally, would fall in the unimaginable or impracticable range for laparoscopy into reproducible robotic procedures whose results will be analyzed here. In 2013, a large retrospective series of robotic pancreatic resections was published. They demonstrated that oncologic and benign disease resections are feasible with a low conversion rate. Robotic distal pancreatectomies have been looked at with good results, especially in splenic preservation due to the wristed instrumentation and multiarm control. (Shrivastava, A. & Menon, M. *et al*. 2002) [16]. The robotic approach to distal pancreatectomy has lower estimated blood loss, higher spleen preservation rates, and a shorter hospital stay compared to laparoscopic approaches. Although robotic hepatic surgery is a challenging procedure, it is further developing, safe, and no different than laparoscopy with similar oncologic outcomes.

Gastric surgical oncology: Refinement takes shape

For the last several years, a number of large improvements have appeared in this quite skill-demanding surgical intervention, especially regarding robotic liver surgery. It follows that the robotic platform overcomes the limitations of laparoscopy, especially in D2 lymphadenectomy, and has been useful in robotic-sown anastomoses and challenging dissections around the gastroesophageal junction or the pyloric region.

Robotic gastric resections may facilitate future laparoscopic resections and decrease operative times for both approaches once the surgeon's learning curve is mastered. (Montalti R,Berardi et.al 2015) [17]. When the learning curve for robotic gastric resections is overcome, the yield from D2 lymphadenectomy increases and becomes superior.

Robotic distal pancreatectomy has also reported excellent outcomes, particularly in splenic preservation due to wristed instrumentation and multi-arm control. Compared with laparoscopic approaches, robotic distal pancreatectomy has lower estimated blood loss, higher spleen preservation rate, and shorter hospital stay despite longer operative times. Despite the challenges associated with robotic hepatic surgery, the field is evolving and is safe, comparable to laparoscopy, and with the same oncologic outcomes despite the difficulties associated with this type of operation. The field is evolving, and the data supports the fact that robotic surgery is safe, comparable to laparoscopy, and has the same oncologic outcomes despite the difficulties associated with this type of operation.

Pediatric surgery: applications despite size

Robotic surgery has been successfully applied to the paediatric population, overcoming limitations because of size. The da Vinci system has been a popular choice for paediatric surgery with applications such as pyeloplasty, fundoplication, and patent ductus arteriosus ligament. Operative time is longer compared with laparoscopy; however, for similar reasons as their non-paediatric surgeon colleagues, the authors prefer the robotic platform. However, they raise concern about the need to adapt the equipment for neonates and to reduce the costs of these procedures. A further, more specialized application of the robotic system in paediatric surgery has also been described with excellent results, comparable to those obtained with the open approach for choledochal cyst excision and biliary reconstruction. The robotic system keeps innovating in their fields when responsible for progress.

The last argument: innovation cannot be stopped

A 2016 review of surgical specialties and General Surgery subspecialties found that adverse events were less frequent in those where the surgical robot was used more often. Most of these events were due to equipment malfunction, not surgical technique. However, surgical judgment should always be the driving force in control of the surgical robot.
A European study in 2013 suggested the expansion of the robotic platform to more subspecialties in General Surgery, shifting the paradigm from the old idea that the surgical robot should only be reserved for highly specialized procedures. Innovation cannot be stopped, as surgeons must prioritize patient safety. Safe innovation becomes a reflection of progress in their specialty. The study suggests that a successful robotic General Surgery program can be implemented in a community hospital by training the surgical team as the surgeon overcomes the learning curve, with improved results seen as the number of cases increases. The study also suggests that the surgical robot can be safely and efficiently used both for complex and simple General Surgery procedures, not just for complex cases. The author's ultimate goal is to remind the international surgical community to appreciate the value of the surgical robot for General Surgery and its multiple subspecialties, while also reminding them to continue learning and improving to benefit patients.

Challenges and limitations:

Following the section on "Challenges and Limitations of Robots in Medical Surgery”

1. **High Cost**

Initial Outlay: Medical robots like the Da Vinci Surgical unit, for example, are expensive, costing millions of dollars. This creates problems in acquiring them for small hospitals or those from third world countries who may find it more expensive.

- **Costs for Maintenance and Upkeep:** Over time, the costs related to maintenance, servicing, and parts replacement will become too heavy on your wallet.
- **Training Costs: Patients are Expensive to Train:** Specific training is needed for surgeons and staff for both the use of these systems, which comes at a premium in terms of cost per unit time.

2. **Complexity of Use**

Steep Learning Curve: Robotic systems are complex; expert surgeons require significant training—up to 100 procedures or for about three months' time in current situations. It has a steep learning curve, and the success of the surgery depends on how good your surgeon is.

User Fatigue: Long surgeries with robotic systems may cause user fatigue and reduce the ability of the surgeon to control over time.

3. **Lack of Tactile Feedback**

- **No Sensory Feedback:** One element that makes traditional surgery one of a kind is the surgeon's capability to sense and respond immediately while carrying out surgical procedures, something still not completely available using robotic systems. Unfortunately, this makes it difficult to know just how much force is being used and can cause tissue injury.
- **Reliance on Visual Cues:** Surgeons must depend most of the time completely upon what they see, which can be restricting to some extent during complex or delicate surgeries.

4. **Technical Limitations**

- **Latency Issues:** Even though the control systems are advanced, there may be minor delays (latency) which can impact how precise the surgery is due to a slight delay between what action your surgeon wants his robot arms to do and when they will actually move.
- **System Failures:** Robotic systems are occasionally prone to systematic technical failures or even system-level malfunctioning, which can present an obstacle during surgery. While backups and override options are critical, they may not be able to cover all of your possible problems.
- **Limited Dexterity in Tight Spaces:** Due to very confined spaces, the robot has limited dexterity, which leads them not to be able to do some kinds of surgeries properly.

5. **Limited Accessibility**

- **Geographical Disparities:** Robotic surgery is available at top-notch medical facilities in the big city/metropolitans, leading to a rural versus urban divide.
- **Difficult to Scale across Surgical Fields:** Complete robotic systems from any one vendor may only be available for particular surgeries, which impair extensive application across various surgical fields.

6. **Resistance to Adoption**

- **Surgeon Resistance:** There are surgeons who may not want to learn the new technology, have doubts about its benefit, or worry that it will replace their job.
- **Cultural Barriers:** There may be areas in which the cultural environment influences patients and healthcare providers to prefer traditional surgery.

Future trends and development in surgical robots

The burgeoning years of surgical robots are seeing the course reset for their future, with technology improvements and a healthy dose of artificial intelligence (AI) on one hand—and better training programs on the other. These advancements will continue to enhance surgical accuracy, minimize invasiveness and broaden access to surgery over a range of specialties.

1. Enhanced Technologies

The future of surgical robotics depends on the advanced imaging technologies to be integrated into them, like Augmented Reality-based high-resolution 3D Imaging. The technologies enable superior visualization of the surgical field and helps to map anatomy more accurately resulting in better surgery. In addition, miniaturizations result in less invasive procedures that mull over dramatically improve recovery times and the trauma experienced by patients.

2. AI and Machine Learning Integrations

Surgical robotics is facing a profound change with the coming of artificial intelligence (Ai) and machine learning that will automate tasks, analyse vast amount of data to improve decision making among others. These could be: Preoperative planning, in-operational assistance and post-operative analysis which will help deliver a safer and efficient surgery with the support of AI systems. One such application is in the development of machine learning algorithms, to objectively assess surgical skills which may help standardize training and assessment for surgeons.

3. Remote surgery & teleoperation

The emergence of devices like surgical robots that will enable tele-surgery is another encouraging trend. This advancement will empower surgeons using other advanced visualization and control technologies to perform surgeries in remote sites, such as those used in the overland surgical system. Findings like these are instrumental in closing the global surgical care gap and improving patient outcomes, even for those living in rural locations.

4. Training and Education

As surgical robots continue to grow in popularity, so do the ways we train & educate surgeons thanks to cutting-edge simulation technologies. Methods Virtual reality (VR) and other immersive training modalities are being incorporated into surgical training programs to improve the performance of trainees on robotic systems. Robotic-assisted procedures are often more technically demanding and have longer learning curves than traditional minimally invasive techniques; training is therefore of the utmost importance as it relates to patient safety, operative outcomes etc.

5. Challenges and Solutions

These advancements are promising, but challenges related to the high acquisition costs equipment and need for specialized training will limit deployment in a clinical setting without changes in patient safety and device reliability. Leasing models, refurbished systems and an emphasis on training are among the solutions being floated to overcome these hurdles and expand use of surgical robots.

6. Future Predictions

For the future development, experts in this field point out that advances will include increased autonomy for surgical robots and more comprehensive safety features as well as better integration into existing healthcare systems to allow optimized workflow from preoperative preparation of surgery until postoperative follow up with patient-centered care. As haptic feedback technology continues to improve, surgeons will one day be able to have a sense of touch while operating - invaluable for their ability to control movement in delicate procedures.

7. Impact in Surgical Care

The benefits of artificial intelligence advancements are likely to be profound, resulting in surgical interventions with diminished risks and greasier patient experiences. With advanced developments in surgical robotics, we will likely see these systems have a central place in the future of surgery worldwide to assist both surgeon performance and patient outcomes.

Case study

The study of medical robotics in surgery is growing rapidly and is changing the way procedures are carried out. Greater accuracy, fewer incisions, less blood loss, and faster patient recovery are all made possible by the employment of robots. Here are some few case studies that highlight the impact of medical robotics in surgery.

1. The da Vinci Surgical System: Prostatectomy

Men with clinically tested positive for prostate cancer are the people who chose the surgical treatment were candidates for this procedure. Patients with the life span of less than 10 years or the people with the Charlson comorbidity score was 3 or greater were excluded. Before surgery, patients go through a detailed evaluation to ensure they're ready for the procedure and to identify any potential risks. This includes checking their prostate health by measuring the level of prostate-specific antigen (PSA) in their blood. Patients also fill out a questionnaire, the International Prostate Symptom Score (IPSS), which helps doctors understand how severe their symptoms are and how much these symptoms are affecting their daily lives. Another important part of the evaluation is assessing the patient's sexual health and overall quality of life. This helps the medical team understand any concerns the patient might have regarding their sexual function or how their condition is impacting their well-being. They also complete an incontinence questionnaire to check if urinary issues are a problem. In addition to these prostate-specific checks, doctors also look at the patient's overall health, particularly any other medical conditions that could complicate surgery. This includes conditions like a history of stroke, brain aneurysms, diabetes, high blood pressure, chronic lung disease (like COPD), or past heart attacks. By considering all these factors, the medical team can plan the safest and most effective surgery for each patient. (Tewari, A, *et al*., 2002) [22].

The Da Vinci Surgical System has revolutionized urological surgeries, particularly prostatectomies. In one case, a 60-year-old male patient with clinically tested prostate cancer undergoes a robot-assisted prostatectomy. The robotic system allowed for precise surgical movements, resulting in minimal blood loss, less post-operative pain, and a quicker recovery compared to traditional surgery. The patient was discharged within 48 hours, with a fast return to normal functions. (Menon, M., *et al*. 2004) [16].

2. Mazor Robotics - Spine Surgery

Medical robots generally fall into three categories: supervisory-controlled, telesurgical, and shared-control. Supervisory controlled robotics let the surgeon to construct the entire procedure beforehand; the robot then carries out the procedure under the surgeon's careful supervision. In telesurgical robotics, the surgeon can operate the robot and its equipment remotely and maintain direct control over the entire surgery. Most of spinal surgery robots are shared-control robots, which indicates that the surgeon and the robot are capable of managing tools and movements at the same time.

In 2004, the SpineAssist, developed by Mazor Robotics in Israel, became the first robot approved by the FDA for spinal surgery in the United States. It's now one of the most commonly used tools in this field. Performing a spinal fusion surgery with the SpineAssist involves five key steps:

Preoperative Planning: The process starts with the surgeon taking detailed 1-mm CT scans of the specific areas of the spine that will be operated on. Using specialized software, the surgeon then maps out the exact path for inserting screws into the spine. The SpineAssist robot uses this information, along with its built-in algorithms, to determine the best screw size and placement. This planned trajectory is saved within the robot.

Preparation in the Operating Room: Once in the operating room, the patient is positioned face down (prone) on the surgical table. A special mounting frame is then attached to the patient's spine. This frame is used to help with the alignment and registration of images during the surgery.

Image Registration: After the frame is secured and markers are placed on the patient's body, six X-ray images (fluoroscopic images) are taken. These images are matched with the preoperative CT scans and stored in the SpineAssist system.

Robot Setup: The robot is then connected to the mounting frame on the patient's spine. It automatically adjusts its arm to follow the pre-planned screw path, ensuring precise alignment.

This process allows for highly accurate and minimally invasive spinal surgeries, enhancing the safety and effectiveness of the procedure. Finally, screws are placed using the guide wires. (D'Souza, M. *Et al*., 2019) [11].

Mazor Robotics' Renaissance system is used for precise spinal surgeries, such as spinal fusion in scoliosis cases. A 45-year-old female patient with severe scoliosis underwent spinal fusion assisted by this robotic system. The technology ensured the accurate placement of screws and rods, reducing surgical time and radiation exposure while promoting a quicker recovery and significant pain relief. (Hyun, S. *et al*. 2017) [12].

3. Cyberknife – Radio surgery for brain tumours

The CyberKnife System is made up of a robotic manipulator with computer control that can operate in six degrees of flexibility and a 6 MV X-band linear accelerator is used, with a dosage rate that can range from 3 to 10 Gy/min depending on the system version. The device includes a circular lamellar collimator with an adjustable aperture (Iris™ Variable Aperture Collimator by Accuray Inc.) and a set of spherical tungsten collimators with apertures ranging from 5 to 60 mm. For treating brain metastases, either a single or multiple fixed collimators, or the Iris collimator, can be utilized. A six-dimensional skull tracking algorithm is used for cerebral indications; it continuously tracks intracranial It targets and automatically adjusts for any shifts in position or rotation of the target during radiation therapy, using the skull's bone structure as a reference. For treating brain metastases, either a nonisocentric or isocentric planning method can be applied. The CyberKnife allows for the delivery of the entire treatment dose with a single treatment utilizing one hundred or more beams or up to five portions. (Kim, R., & Lunsford, D. G. *Et al*.,2012) [14].

CyberKnife is a minimally invasiverobotic radio surgery system is use for the treatment of brain tumors. In a case involving a 50-year-old female with an inoperable brain tumor, The CyberKnife system delivered high-dose radiation directly to the tumor with pinpoint accuracy, avoiding damage to the healthy tissue around it. The patient showed significant tumor reduction with minimal side effects and no damage to adjacent brain structures. (Adler, J. R *et al*.1999).

Regulatory and safety consideration of surgical robots

1. Framework and level of autonomous

Surgical robots can be classified as level II medical devices, based on the level of their invasiveness, and equivalents through the 510(k) premarket notification pathways. The USA Food and Drugs Authority's response to the regulation of medical device framework was for the equipment that requires direct surgeon control and lacks true autonomy to shift to robotic-assisted surgical devices. The same job was done in Europe by Conformite’ Europe`enne (CE) certification under the medical device directive. The level of autonomy in surgical robots (LASR) is categorized based on their decision-making capacities.

2. Safety standard

Surgical robots must adhere to some of the safety standards including ISO14971 and the IEC660601 standard series deals with risk management and essential performance of medical devices, also in the other hand IEC80601-2-77 series deals with the level of safety and performance for health care providers and patients, all this way help to build the trust to them.

3. Safety protocols in practice

This ensures that there is no risk associated with surgical robots, and involves comprehensive pre-operative assessment, meticulous intraoperative monitoring, and detailed post-operative evaluation. Involves in the protocol effective integration of surgical robots in clinical settings. Therefore, for advanced technological capability that maintains patient safety.

4. Training and credentialing

This deals with surgical procedures, Surgeons must undergo extensive training that includes simulation and hands-on experience with the robotic equipment, ensuring that they are adequately prepared for any challenges during surgery, and optimizing the patient safety outcome.

5. Risk management

This deals with device malfunction and procedural challenges such as unintended retained foreign objects (URFOs) (Stefanis Huffman E.M, Collins J.W., *et al* 2020), therefore basic medical institutions or organizations must establish the police and sustainable performance evaluations to standardize the process during an operation room. This helps to maintain safety by regulating audits and monitoring to know the potential safety issues and enable proactive risk management strategies.

Ethical and social implication

1. Patient Safety Concerns

One of the primary ethical implications surrounding surgical robots is patient safety. While these systems can enhance surgical precision and improve outcomes, they also introduce new risks such as technical malfunctions and software errors that could jeopardize patient safety124. Ensuring rigorous testing and maintenance of robotic systems, along with continuous surgeon training, is essential to mitigate these risks and uphold the quality of care

2. Informed Consent

Informed consent plays a crucial role in the ethical deployment of robotic surgery. Patients must be adequately informed about the unique aspects of robotic procedures, including potential risks and benefits compared to traditional surgery. This requirement necessitates effective communication from surgeons to ensure patients understand the complexities involved and can make informed choices about their healthcare.

3. Job Displacement

Surgical robots raise significant ethical and social concerns regarding job displacement among healthcare professionals. As robotic technology becomes more prevalent, roles within surgical teams may evolve or diminish, leading to fears of redundancy for skilled staff12. To address these implications, proactive approaches for retraining and redefining job roles must be considered to support the workforce through these transitions 15.

4. Equity in Access to Care

Another critical aspect is the potential for inequities in access to surgical robots. The high costs associated with implementing robotic systems can create disparities in healthcare access, particularly for underserved populations12. Ethical practice demands initiatives to make these technologies more affordable and accessible to ensure that diverse populations can benefit from advanced medical technologies.

5. Erosion of the Human Touch

The rise of robotic surgery could lead to a perceived erosion of the human touch in patient care. As surgeons operate from a distance through robotic consoles, there are concerns about losing the emotional and empathetic aspects of medical care. Balancing technological advancement with maintaining the human connection in healthcare remains a vital ethical challenge.

6. Regulatory Standards

The rapid evolution of robotic surgical technology emphasizes the necessity for robust regulatory frameworks and standardization of practices. Currently, a lack of uniform standards across institutions may lead to discrepancies in the quality of care provided1. Establishing clear guidelines for the ethical conduct of robotic surgery, including training and certification processes, is crucial for ensuring patient safety and trust in these technologies 12.

7. Autonomy and Accountability

The increasing autonomy of surgical robots raises questions about accountability in surgical outcomes. Determining who is responsible when adverse events occur, whether the surgeon operating the robotic system or the technology itself, poses significant ethical considerations28. Addressing these questions is important for maintaining ethical standards in surgical practices and protecting patient rights.

Conclusion

One of the most important steps in health care has been the inclusion of robotics inside surgical procedures. Surgical robotics has advanced and evolved to the point where surgeons are now able to do minimally invasive procedures with precision accuracy in a myriad of specialties, from urology all the way through neurosurgery. These technologies have not only improved patient outcome but also broadened the horizon possible in complex surgeries.

Notwithstanding the many benefits, which include cost implications and technical logistics, as well as high learning curve obstacles continue conforming hurdles retains expansive budget to outspread adoption. Satisfying this requirement for complete autonomous operation was difficult and the lack of tactile feedback as well a few system failures highlight that more innovation is needed to ensure safe operations of these systems.

In the next few years, more revision will be undergone in AI technology and improved imaging for machineries like surgical robotics as well with extensive possibility of remote surgery. As they continue to develop, these technologies are likely to become increasingly affordable and widely available, ultimately being incorporated into everyday surgical practice which has the potential for safer and more rapid surgery.

Therefore, although the march of surgical robotics is still in progress… it seems inevitable that surgery will never be the same. These limitations will be addressed eventually by the latest advancements, making robotic surgery an even more important part of evidence-based medicine.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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