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Robotic Surgery: Transforming Healthcare Landscape

Akshara Reghunath K, MBE.

aksharareghunath1999@gmail.com

Abstract: *Robotic surgery has come to light as an innovative advance in medicine that has drastically changed the face of healthcare. Patients can benefit from this technology's unparalleled precision, control, and minimally invasive choices to its integration of sophisticated robotics, artificial intelligence, and accurate surgical methods. With the use of robotic devices, surgeons may now conduct difficult procedures with increased accuracy, less trauma, and quicker recovery times. Shorter hospital stays and reduced complication rates are the results of this better patient outcome. The article examines the development of robotic surgery, its present uses in a range of medical specialties, and its effects on patient care and the larger healthcare system. It also addresses the difficulties and prospects for robotic surgery in the future, particularly how it might be integrated with cutting-edge innovations like telemedicine and machine learning, which have the potential to completely transform the surgical field. This analysis highlights how robotic surgery can change healthcare delivery and improve patient outcomes. It also shows how robotic surgery has the potential to become a new norm in modern medicine.*

Keywords: *Robotic Surgery, Minimally Invasive Surgery, Surgical Precision, Da Vinci Surgical System, Future of Robotic Surgery, Technological Advancements, Surgical Robotics.*

INTRODUCTION

"*Robotics isn't about machines; it's about creating companions that enhance human capabilities."* – Raffaello D'Andrea.[1]

"Our future in surgery lies not in blood and guts, but in bits and bytes!"[2]

- Colonel Richard Satava[3]

*Address correspondence to: Akshara Reghunath K. Masters in Bioethics (MBE). ICREP, CUSAT, KOCHI. Ernakulam, Kerala. Email: aksharareghunath1999@gmail.com

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[1] Sushmita Nibandhe, '15 Robotics Quotes to Showcase the Future of Mankind' (*Businessapac*) <https://www.businessapac.com/robotics-quotes/#:~:text=%E2%80%9CRobotics%20isn't%20about%20machines,%E2%80%9D%20%E2%80%93%20Raffaello%20D'Andrea.> accessed 20 March 2024.

[2] W Douglas Boyd and Kenneth D Stahl, 'The Janus Syndrome: A Perspective on a New Era of Computer-Enhanced Robotic Cardiac Surgery' (2003) 126 The Journal of Thoracic and Cardiovascular Surgery 625.

[3] SANT´ANNA Roberto T and others, 'Robotic Systems in Cardiovascular Surgery' [2004] Heart Institute, Rio Grande do Sul/University Foundation of Cardiology.

Surgery, however, is a necessary procedure to regain a normal living life in a variety of emergencies, such as accidents, cardiac arrest, and stroke. Furthermore, surgical innovations significantly contribute to the prevention of both acute and chronic illnesses, enabling patients to live longer and better lives. Even with successful surgeries, people continue to fear large incisions, pain, infection, and extended hospital stays. As an alternative to open surgery, minimally invasive surgery (hereinafter, MIS) has become a significant trend in general surgery.

For a faster recovery, minimal incisions are used in MIS instead of large incisions in the body.[4]Technology continually challenges the boundaries of healthcare, redeveloping methods of treatment and changing conventional procedures. Among these innovations, robotic surgery stands out as the most innovative since it improves patient outcomes, accuracy, and efficacy. This approach has revolutionized surgical practices in a variety of medical fields of study, including urology and cardiothoracic surgery, by utilizing cutting-edge robots. The development of the technology and telemanipulation technology in the late 20th century is connected with giving rise to robotic surgery. A turning point was reached when the “da Vinci Surgical System” emerged in the early 2000s, bringing RAS into the general public.[5] This revolutionary platform, created by Intuitive Surgical, marked the beginning of a new age in surgical accuracy by providing surgeons with improved accuracy, vision, and control.[6]

Future developments in robotic surgery appear promising for additional innovation and improvement. Robotic platforms will be enhanced by developments in virtual reality, machine learning, and artificial intelligence. These developments will make it possible for surgical visualization to be realistic and for autonomous decision-making to occur. Furthermore, the addition of haptic feedback methods could potentially close the gap between robotic manipulation and tactile sense, improving the surgeon's precision and tactile perception.[7]

RS is discussed in detail in this chapter, providing a thorough overview that explores its historical development. A detailed comparison is made between robotic surgery and conventional surgical techniques, taking into account a number of important factors like cost, surgical complications, recovery time, and long-term survival rates.[8] In addition, the study looks at how advances in haptic feedback technology help surgeons perform better when doing robotic surgeries. Robotic surgery has several advantages over traditional methods, such as less damage to surrounding tissues and more accurate incisions. It is characterized by precision and less invasiveness. The study clarifies the cost of using robotic surgical equipment. By explaining these aspects, this chapter highlights the critical role that robotic surgery plays in modern healthcare.

1.1 OVERVIEW ABOUT ROBOTIC SURGERY

Surgical navigation, pre-operative planning, and surgical procedure execution can all be assisted by Computer-Assisted Surgical Systems (hereinafter, CAS). One kind of CAS is the RAS. RAS devices, sometimes known as "robotic surgery," enable a surgeon to carry out a variety of surgical operations through one or more microscopic (minimally invasive) incisions in the patient's body by controlling and moving surgical instruments with the use of computer and software technologies.[9]

‘Robotic surgery’, also known to as ‘Robot-Assisted Surgery ‘(RAS), is a MIS approach in which surgeons are supported by specialized robotic devices to carry out treatments with control and precision. These systems comprise

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[4] Karthikeyan, K B, ‘Design Development and Control of Robotic Assisted Minimally Invasive Surgical System’ (project thesis, VIT University 2019).
[5] Tiffany Leung and Dinesh Vyas, ‘Robotic Surgery: Applications’ (2014) 1 American Journal of Robotic Surgery 1.
[6] Kavyanjali Reddy and others, ‘Advancements in Robotic Surgery: A Comprehensive Overview of Current Utilizations and Upcoming Frontiers’ (2023) 15 Cureus e50415.
[7]Yeisson Rivero-Moreno and others, ‘Autonomous Robotic Surgery: Has the Future Arrived?’ [2024] Cureus<https://www.cureus.com/articles/214232-autonomous-robotic-surgery-has-the-future-arrived> accessed 21 March 2024.
[8] ‘National Leaders in Robotic-Assisted Surgery’ <https://health.ucdavis.edu/surgicalservices/roboticsurgery/> accessed 12 March 2024.
[9] ‘Computer-Assisted Surgical Systems’ (21 June 2022) <https://www.fda.gov/medical-devices/surgery-devices/computer-assisted-surgical-systems#2>.

a high-definition vision system that offers an enlarged three-dimensional picture of the surgical site, robotic arms fitted with surgical instruments, and a surgical console controlled by the surgeon. As an alternative to open surgery, MIS has become a major force in general surgery. Robotic surgery, as compared to traditional open surgery and conventional laparoscopy, improves operation safety and effectiveness by combining robotic technology with the surgeon's expertise. [10]

Robotic surgery has gained popularity in many medical fields, including neurosurgery, orthopedics, gynecology, spine surgery, endocrine surgery, oncology, gastrointestinal, cardiothoracic, gynecology, [11]oncology, otolaryngology (head and neck) , urologic surgery, radical prostatectomy,[12] mitral valve repair idea transplant, coronary artery bypass, hip replacement, nephrectomy, hysterectomy, gall bladder removal, pyloroplasty, ophthalmology, plastic surgery, pediatric surgery, thoracic surgery, and dentistry.[13] Its broad acceptance in a variety of medical fields attests to its adaptability and widespread availability in surgical operations across the entire world.

Surgical robotic systems are typically divided into two groups based on how autonomous they are. The first category, known as autonomous systems, carries out designated duties autonomously with minimal assistance from the operator. On the other hand, nonautonomous systems attempt to recreate the surgeon's movements through hands-on or master/slave teleoperation configurations. [14][15]

Robotic systems for medical and surgery differ in:[16]

- Computer Assisted Surgical Planning (hereinafter, CASP) and Computer Assisted Surgical Execution (hereinafter,CASE) combine robotics and computer technology.
- Surgical augmentation devices that get around many of the drawbacks of traditional surgery by increasing human sensory-motor capacities.
- Systems for surgical assistance that collaborate with a surgeon to automate a lot of the work done by surgical assistants.

The da Vinci® system was approved by the Food and Drug Administration (hereinafter, FDA) in 2000, and Intuitive Surgical went on to become the market leader in robotic surgery in the United States (hereinafter, US).[17] Closely following is Stryker, who joined the market by acquiring MAKO® Surgical Corp. and providing the Rio® Robotic Arm Interactive platform. Smith & Nephew's focus on robotically assisted knee replacements gives them a prominent position. With its CyberKnife® robotic radiosurgery system, Accuray stands out, and Medtronic is the industry leader in robotic spinal surgery. For orthopedic and neurosurgery spine operations, Globus Medical provides solutions. Auris Health is a division of Johnson & Johnson that specializes in robotic vascular catheter technologies. With its ROSA® robotic system, which it acquired from MedTech, Zimmer Biomet excels in orthopedic, spinal, and neurosurgical treatments. These leading businesses represent innovation and progress in the surgical robotics industry in the United States.[18]

With a few notable exceptions, including the Cyber-Knife system (Accuray, CA, United States of America (hereinafter, USA)) used in radiosurgery and the Robodoc (Curexo Technology Corporation, CA, USA) used in Total

[10] Reddy and others (n 10).
[11] Pai and others (n 3).
[12] Elizabeth Z Goh and Tariq Ali, 'Robotic Surgery: An Evolution in Practice' (2022) 2022 Journal of Surgical Protocols and Research Methodologies snac003.
[13] ibid.
[14] Adam Ang, 'Robotic Surgery Trickles down to India's Public Health Sector' *Healthcare IT News* (19 January 2024) <https://www.healthcareitnews.com/news/asia/robotic-surgery-trickles-down-india-s-public-health-sector> accessed 17 March 2024.
[15] N Sharkey and A Sharkey, 'Robotic Surgery: On the Cutting Edge of Ethics' (2013) 46 Computer 56.
[16] Dr Drishya Viswam, 'Robotic Surgery: Ethical Legal Concerns' in Dr Vani Kesari A (ed), *Health care and Bioethics- A compendium on BIoethical Perspectives* (Directorate of Public Relations and Publications for ICREP, CUSAT).
[17] Girdhar Singh Bora and others, 'Robot-Assisted Surgery in India: A SWOT Analysis' (2020) 36 Indian journal of urology: IJU: journal of the Urological Society of India 1.
[18] 'Top 8 Robotic Surgery Companies in the United States' <https://idataresearch.com/top-robotic-surgery-companies-in-the-united-states/> accessed 16 March 2024.

Knee Arthroplasty (here in there after TKA), the majority of surgical robots fall into this second group. This is mostly because of the significant technical challenges associated with carrying out automated activities in medical interventions with the required dependability because of the urgency of the area.[19]

In the USA, a database known as "The Manufacturer and User Facility Device Experience (hereinafter, MAUDE)" was developed. According to the database between 2000 and 2013, the USA performed 1.745 million robotic surgeries.[20]MAUDE gets reports of adverse events that appear to be related to medical technology. According to MAUDE, 10,624 adverse events (deaths, injuries, malfunctions and other issues) were reported in the United States involving robotic systems from 2000-2013. 0.6% of robotic surgical procedures had adverse effects.[21]

In 2006, the All-India Institute of Medical Sciences in New Delhi became the first institution in India to install urologic robotics.[22] Currently, over thirty medical centers in India are offering advanced robotic surgery. Twelve of these establishments, *All India Institute of Medical Sciences* (hereinafter ,AIIMS), Apollo, Max Hospital, Rajiv Gandhi Cancer Institute, Sir Ganga Ram Hospital, Fortis, and Medanta, are located in northern India. In western India, eight hospitals—Jaslok Hospital, KokilabenDirubhai Ambani Hospital, Sir HN Reliance Foundation Hospital, and Tata Memorial Hospital are utilizing surgical robotics. India's Krishna Institute of Medical Sciences (hereinafter ,KIMS) in Hyderabad is home to surgical robots. Seven are located in southern India, and they include Aster Mendicity, Kochi, the KIMS, the Amrita Institute of Medical Sciences, and Apollo Hospitals in Chennai and Hyderabad. Kolkata's Apollo Gleneagles Hospital is one surgical robotics user.[23]

The Intuitive Surgical Company's "da Vinci Surgical System" is used by Apollo Adlux Hospital in Angamaly, Amrita Hospital in Ernakulam, Aster Medcity in Ernakulam, Daya General Hospital in Thrissur, Sun Medical and Research Centre in Thrissur, St. Gregorios Medical Mission Multi-Specialty Hospital in Thiruvalla,[24] and KIMS Hospital in Trivandrum,[25] among other hospitals in Kerala, to provide robotic surgical services. While Venkateshwar Hospital in Delhi chooses the Hugo RAS System, Swagat Hospitals in northeastern India embraces cutting-edge technology with the CMR surgery's Versius System in its robotic surgery theater, illustrating different approaches to advanced medical care in the private sector.[26]

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[19] Nima Enayati, Elena De Momi and Giancarlo Ferrigno, 'Haptics in Robot-Assisted Surgery: Challenges and Benefits' (2016) 9 IEEE Reviews in Biomedical Engineering 49.
[20] Fatih HitamiUsluogullari, SitkiTiplamaz and NesimeYayci, 'Robotic Surgery and Malpractice' (2017) 43 Türk ÜrolojiDergisi/Turkish Journal of Urology 425.
[21] ibid.
[22] Bora and others (n 21).
[23] Dr Vikrant Yadav, 'Robotics in Health Care: Who Is Liable?' [2018] SSRN Electronic Journal <https://www.ssrn.com/abstract=3598028> accessed 26 March 2024.
[24] 'Robotic Surgery' <https://www.drarungastrosurgeon.com/robotic-surgeon-in-thrissur/>.
[25] 'Advanced Robotic Surgery Unit Inaugurated at KIMSHEALTH' *The Hindu* (1 March 2024) <https://www.thehindu.com/news/national/kerala/advanced-robotic-surgery-unit-inaugurated-at-kimshealth/article67904641.ece>.
[26] 'Robotic Surgery Trickles down to India's Public Health Sector' (n 18).

Figure 1. Robotic Assisted Surgery

27

1.1.1 Da-Vinci System

The most popular robot-assisted surgery platform for minimally invasive operations is still the da Vinci Surgical System, which was created and commercialized by Intuitive Surgical, Inc. This Intuitive Surgical device revolutionized minimally invasive surgery by giving surgeons better vision, flexibility, and precision. The rapid expansion of robotic-assisted surgeries was made possible by the da Vinci Surgical System's quick acceptance in a variety of surgical fields. [28]

The da-Vinci system has mainly of 3 subsystems [29]

i. The patient side cart
ii. The surgeons console
iii. The vision carts

The da Vinci system has several robotic arms that are equipped with surgical tools. Compared to conventional laparoscopic equipment, these arms offer a greater range of motion and closely replicate the surgeon's hand movements. From a surgical console in the operating room, the surgeons manipulate the robotic arms. The hand controls on the console enable the surgeon to accurately handle the instruments while viewing a three-dimensional (hereinafter ,3D) image of the surgical field. The robotic arms are equipped with high-definition cameras that offer a

[27]'Minimally Invasive Surgery' <http://bangaloreadvancedurology.com/service/laparoscopic-robotic-surgery/>.
[28] Alex Macario and Phi T. Ho, 'Robotic Technology' in Alan David Kaye and Richard D Urman, *Perioperative management in robotic surgery*, vol chapter 3 (Cambridge University Press 2017).
[29] Mahdi Azizian, May Liu, Iman Khalaji, Simon DiMaio, 'The Da Vinci Surgical System' in Jaydev P Desai, *The Encyclopedia of Medical Robotics*, vol 1.

thorough view of the surgery site.[30]By providing 3D imagery and magnification, the vision system helps the surgeon better navigate complex anatomical processes. [31]

Robotic arms replicate the same movements of a surgeon's hands, functioning as the mechanical limbs of complex surgical systems. Their capacity to navigate through the small, complex places inside the human body is a crucial part of their advanced design, which makes it possible to carry out difficult surgical procedures. These robotic arms, which are armed with specialized surgical instruments, provide surgeons with flexibility and precision, enabling them to manipulate tissues and carry out tasks with never-before-seen accuracy. The remarkable capabilities, robotic arms transform surgery by increasing accuracy, reducing invasiveness, and eventually improving patient outcomes.[32]

Surgeons can precisely coordinate complex procedures with an enhanced interface provided by the surgical console, which acts as a nerve center for robotically assisted surgeries. With its easy-to-use hand controllers and sensitive foot pedals, the console allows surgeons to precisely perform complex operations with robotic arms positioned inside the patient's body. The console provides surgeons with a clear 3D representation of the surgery site via smooth integration with high-definition screens, providing crucial information for well-informed decision-making. When combined, these characteristics improve surgical results and give surgeons more confidence and flexibility to execute procedures, which in turn benefits patients by reducing invasiveness and promoting better recovery.[33]

A key component of robotic surgical setup is the vision system, which gives surgeons necessary high-definition 3D imagery of the operating field. Through the provision of an enlarged and finely detailed view of the surgical field, this technology enables surgeons to perform precise incisions and complex operations. Because of its clarity, surgeons can more easily and confidently navigate through complex anatomical structures, improving the overall precision of surgical procedures. This technical breakthrough not only improves surgical results but also opens the door for more developments in the field of minimally invasive surgery, which advances the provision of healthcare.[34]

[30] 'Apollo Robotic Surgery' <https://apolloroboticsurgery.com/#:~:text=Robotic%20surgery%20is%20a%20type%20of%20minimally%20invasive%20surgery%20that,of%20laparoscopic%20and%20computer%20technology.> accessed 26 March 2024.
[31] 'The Da Vinci Surgical System' (n 32).
[32] Reddy and others (n 10).
[33] ibid.
[34] ibid.

Figure 2. Five Model of a Vinci Surgical System

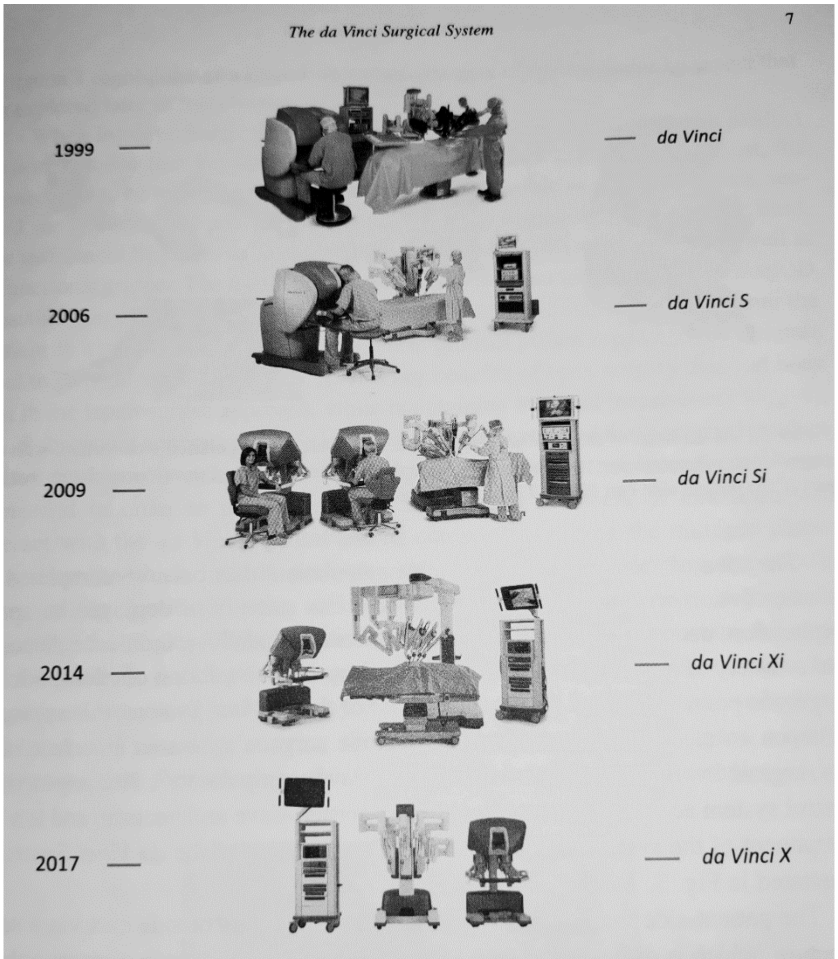

Figure 2. Five models of the *da Vinci* Surgical System (© 2017 Intuitive Surgical, Inc.).[35]

1.1.2 Haptic Feedback

The general term for touch feedback is haptics, and it can refer to both cutaneous tactile which is related to the skin and kinesthetic force feedback which pertain to the positions and forces of the joints and muscles. Force, distributed pressure, temperature, vibrations, and texture are all included in haptics. It is defined generally in the robotics and virtual reality field as actual and simulated touch interactions in a variety of combinations involving humans, robots, and real, far away, or simulated environments. The surgeon uses a long shaft to sense the instrument's interaction with the patient in manual MIS, which minimizes force signals and eliminates tactile cues. Increased intra-operative hazards are associated with this haptic feedback deficiency in MIS.

In RAMIS, the aim of haptic technology is to enable "transparency," whereby the surgeon feels as though he is making physical contact with the patient instead of manipulating a remote device. In order to obtain haptic information,

[35] 'The Da Vinci Surgical System' (n 32).

the patient-side robot must have artificial haptic sensors. The surgeon will then receive the information using haptic displays.[36]

RAS provides medical professionals useful tools that improve patient outcomes by reducing stress during surgery. While one of the most frequently mentioned drawbacks of RAS is the lack of tactile sensation.[37]As is typically the case in the world of medical research, patient safety plays a crucial role in the debate over the significance of haptic feedback in MIS. when haptic input was lacking, tissue movement occurred during handling actions, resulting in tissue injury.[38]

Throughout years of comprehensive study on tactile feedback, there are still no feasible tactile display systems that can effectively and compactly provide distributed information to the skin for a range of applications. Robotic-Assisted Minimally Invasive Surgery (hereinafter, RMIS) haptic feedback systems are still in the research and development stage and also training using haptic feedback techniques is still in its infancy. Most only offer force feedback that is not very accurate. Sensing forces applied to the patient is currently the main challenge. There are a few tactile feedback RMIS systems available, but more research is needed to determine how useful they are for clinical settings. Sensing and displaying tactile information that is distributed spatially is especially challenging. There is no established cost-benefit ratio for haptic feedback in RMIS.[39]

1.2 HISTORICAL OVERVIEW AND DEVELEOPMENT OF ROBOTIC SURGERY

Sushruta-Samhita,Ancient India's text which is the main source of surgical knowledge.[40] Sushruta is known as the "Father of surgery"[41]and "Father of Plastic Surgery"[42] who lived sometime between 700 and 600 Before Christ (hereinafter, B.C.). Sushruta has divided surgery into eight categories:

Vsraya (evacuation),
Ahrya (extraction),
Esya (exploration),
Lekhya (scarification),
Vedhya (puncturing), and
Sivya (suturing).

Sushrutha says that "the principles of surgery are accurate planning, hemostasis, and skillful performance. Famous surgeon Sushruta described a good surgeon as someone who is brave, calm, has a steady hand that is free from sweating or shaking with fear and knows how to use sharp instruments to get results that are in the best interests of the patient. The surgeon should treat each patient with the utmost care and attention, treating them with compassion comparable to that of a parent. This is because the patient has placed a great deal of faith in them. "[43]

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[36] Allison M Okamura, 'Haptic Feedback in Robot-Assisted Minimally Invasive Surgery' (2009) 19 Current Opinion in Urology 102.
[37] Max Bergholz, Manuel Ferle and Bernhard M Weber, 'The Benefits of Haptic Feedback in Robot Assisted Surgery and Their Moderators: A Meta-Analysis' (2023) 13 Scientific Reports 19215.
[38]OaJ van der Meijden and MP Schijven, 'The Value of Haptic Feedback in Conventional and Robot-Assisted Minimal Invasive Surgery and Virtual Reality Training: A Current Review' (2009) 23 Surgical Endoscopy 1180.
[39] Okamura (n 39).
[40] The Editors of Encyclopaedia, 'Sushruta Indian Surgeon', *Britannica*<https://www.britannica.com/biography/Sushruta>.
[41] Vibha Singh, 'Sushruta: The Father of Surgery' (2017) 8 National Journal of Maxillofacial Surgery 1.
[42] Joshua J. Mark, 'Sushruta', *World History Encyclopedia* (2018) <https://www.worldhistory.org/sushruta/>.
[43] Singh (n 44).

The Czech playwright Karel Capek first used the word "robot" in his 1921 play Rossom's Universal Robots (hereinafter, RUR). It was first performed in France, Paris. In that play, small, manufactured, anthropomorphic creatures obediently followed their master's instructions. These creatures were strictly referred to as ‘robotnic’ from the Russian and Czech terms ‘robota’, which mean "drudgery" and "hard work."[44]

The term "robotics" was first used by Isaac Asimov in 1938 in his short tale "Runaround" for Super Science Stories Magazine. After that, in 1942, a collection of short stories titled "I, Robot" was published, which consisted of robots fighting against their human masters. Asimov defined three laws controlling robot behavior using the term robotics:

Law 1: A robot is not allowed to hurt people or, by standing by, permit people to suffer injury.
Law 2: A robot must comply with human commands, unless doing so would violate the first law.
Law 3: As long as it doesn't violate the first or second laws, a robot must defend its own existence.[45]

In 1954, Devol and Engelberger created the first programmable robot known as Unimate and coined the term "universal automaton" for it. Later, Engelberger created Unimation, the first robotics company in history. Stanford University introduced a robotic arm with electrical power in 1970. The Tomorrow Tool, or T3, was the first commercially available minicomputer-controlled robot created by Richard Hohn in 1973. With the intention of commercializing the computer-controlled robotic arm developed by the Stanford research team, Scheinman founded the Vicarm corporation in 1974. The National Aeronautics and Space Administration (hereinafter,NASA) intended to utilize this robotic arm on the Viking space missions. In 1978, Unimation create the Programmable Universal Machine for Assembly (hereinafter, PUMA) with ongoing assistance from General Motors.[46] As the first surgical robot to operate on a real patient, was the "PUMA 200" made its official release on April 11, 1985. Unimation, PUMA was an industrial robot having "shoulder," "elbow joints," and "wrists" that resembled those of a human worker. It was first designed to facilitate repeated yet accurate movements in material handling and assembly. Kwoh et al. conducted the first robotic surgical surgery, known as PUMA 200, at Memorial Medical Center in Long Beach, California. The technique involved a stereotactic brain biopsy. This was the first "robotic surgery," bringing science fiction into the realm of clinical practice. [47] PUMA 560 was among the first medical surgery robots. There are currently many surgical robots on the market, including the Da Vinci robot from Intuitive Surgical, Inc., the Zeus robot from Computer Motion, Inc. for "Minimally Invasive Surgery," the Acrobat robot from Acrobat Company Ltd., and the Caspar robot from U.R.S.-Ortho GmbH for hip and knee replacement.[48]

Computer Motion created the first master-slave robotic system in 1995. This robotic system is made up of a robotic surgical system (slave) and an input console (master). There were three distinct arms to the *ZEUS Robotic Surgical System* (here in there after ZRSS). The first arm gave the surgeon a view of the operating site and was a voice-activated AESOP. The surgeon's hand movements might be replicated by the other two arms, which could also hold a range of equipment.[49] The American Computer Motion's AESOP® and ZRSS were the first to be used in general surgery. Following an extended legal battle, American Computer Motion and its main competitor, Intuitive Surgical, which had been established eight years earlier, merged in 2003.The business created multiple generations of multi-arm, master-slave robots to guard its goods.[50]

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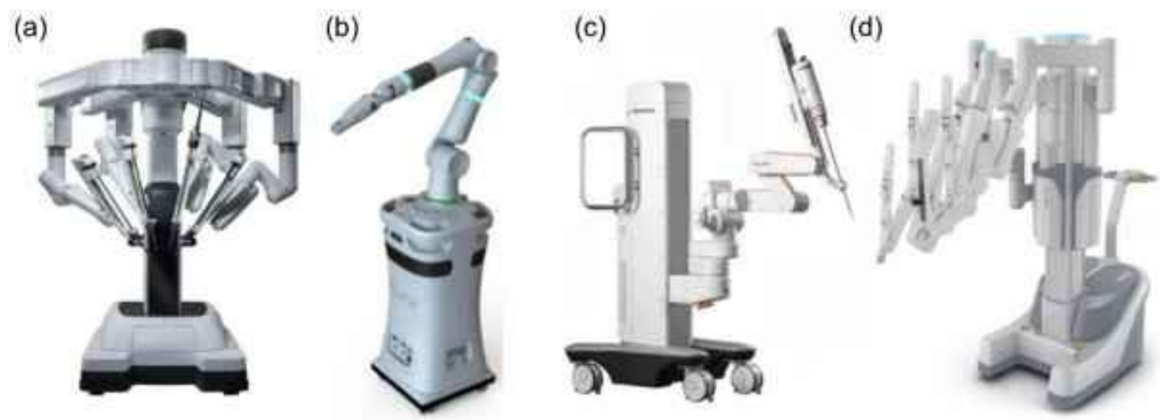
[44] Christine G Gourin and David J Terris, ‘History of Robotic Surgery’ in RusellaA Faust (ed), *Robotics in Surgery- History, Current and Future Applications* (Nova Science Publishers 2007).
[45] ibid.
[46] Mohsen Shahinpoor and Siavash Gheshmi, *Robotic Surgery: Smart Materials, Robotic Structures, and Artificial Muscles* (Pan Stanford Publishing 2015).
[47] Manak Sood and Stefan W Leichtle (eds), *Essentials of Robotic Surgery* (Spry Publishing 2013).
[48] Viswam (n 20).
[49] Alan David Kaye and Richard D Urman (eds), *Perioperative Management in Robotic Surgery* (Cambridge University Press 2017).
[50] Francesco Marchegiani and others, ‘New Robotic Platforms in General Surgery: What’s the Current Clinical Scenario?’ (2023) 59 Medicina (Kaunas, Lithuania) 1264.

Later, Taylor (2006) created ROBODOC to carry out surgical procedures related to orthopedics. Assisting a surgical robot during a successful hip replacement procedure under a surgeon's supervision, ROBODOC made history. As of right now, the FDA has only authorized ROBODOC as a platform for orthopedic surgery Harvey Craig (2016). Furthermore, ORTHOPILOT a computer-aided navigation system was found to be effective in precisely carrying out surgical operations.[51]

Using the Smart Tissue Autonomous Robot (hereinafter, STAR), Shademan et al. (2016) demonstrated their ability to perform completely autonomous robotic stitching inside a living pig's intestine. In several ex vivo and in vivo surgical tasks, STAR quantitatively outperformed human surgeons, despite the fact that the experiments were carried out in a highly controlled environment. For the first time, these experiments showed the early clinical potential of an autonomous soft-tissue surgical robot. In contrast to traditional surgical robots, which are now widely used in certain subspecialties and are directed by humans in real time, STAR was operated by Artificial Intelligence (hereinafter ,AI) algorithms and received information from a variety of haptic and visual sensors.[52]

[53]*Figure 3. Rigid-type surgical robot for multi-port surgery;* ***(a)*** *da Vinci Xi* ***(b)*** *Versius****(c)*** *Hugo™ RAS* ***(d)*** *Revo-i*



1.3 ROBOTIC SURGERY AND TRADITIONAL SURGERY: A COMPARISON

For many years, the most basic and successful type of surgery in medicine was conventional surgery, also known as open surgery. It involves careful planning, preparation, and execution. In this position, the patient is ready to undergo surgery on the operating table in the proper posture. In order to reduce the patient's pain from the procedure, a suitable kind of anesthesia and pre-operative drugs are also administered. Later, the patient has an incision made on their skin to provide access to their internal organs for the purpose of performing surgery. When the procedure is finished, the skin is sutured, leaving a large scar on the skin. In most cases, the length of recovery following this kind of surgery is determined by the part of the body being operated on, the kind of anesthesia used, and other factors.[54]

Due to its ability to reduce operative trauma damage without sacrificing the advantages of traditional surgery, the term "MIS" has gained widespread recognition. As per Matt Ritter (2007), the surgeon performing the surgery in MIS makes three or more small incisions. By using a trocar to enter the surgical cavity, these incisions—known as ports or

[51] 'Design Development and Control of Robotic Assisted Minimally Invasive Surgical System' (n 8).
[52] Sandip Panesar and others, 'Artificial Intelligence and the Future of Surgical Robotics' (2019) 270 Annals of Surgery 223.
[53]Minhyo Kim, Youqiang Zhang and Sangrok Jin, 'Soft Tissue Surgical Robot for Minimally Invasive Surgery: A Review' (2023) 13 Biomedical Engineering Letters 561.
[54] 'Design Development and Control of Robotic Assisted Minimally Invasive Surgical System' (n 8).

cannulas allow access to the MIS instruments and digital camera. To avoid damaging the tissues, trocars are utilized in this situation. Using carbon dioxide (CO2) inserted through trocars to create a surgical environment, pneumoperitoneum is the first step in a laparoscopic procedure's initialization process.[55]

Comparing robotically assisted endoscopic surgery with traditional endoscopic surgery in the context of minimally invasive surgery, there are minor variations, but the general idea of MIS (such as working with few incisions) is the same in both RAS and Conventional Endoscopic Surgery (hereinafter,CES). The most evident one is that with RAS, a surgical robot is positioned between the surgeon's operating hands and the endoscopic surgical instruments which can be called as "the master-slave principle." Seated comfortably in a surgical operating console (master), the surgeon executes the actions by translating them into the arms of a MIS robot (slave). Both CES and RAS can benefit from the same common MIS benefits, which include decreased mortality, decreased infection rates, less pain, quicker recovery, and enhanced appearance.[56]

1.3.1 Advantages of Robotic Surgery

Some benefits of robotic surgery include better patient outcomes, fewer complications, and faster recovery times. The details are as follows.

i. **Precision:** With robotic devices, surgeons may perform complex jobs with submillimeter accuracy and precision in surgical procedures. By lowering the chance of difficulties and postoperative problems, this accuracy ultimately benefits patients by minimizing tissue damage and optimizing surgical outcomes. Surgeons can navigate delicate anatomical structures with greater confidence and improve surgical success rates and patient recovery by precisely managing robotic equipment. The accuracy provided by robotic surgery highlights the revolutionary influence of robotic technology in contemporary healthcare practice by improving patient safety and outcomes as well as the overall efficiency and effectiveness of surgical procedures.[57] Robotic technology is used by surgeons to carry out complex and delicate surgeries with incredible precision that exceeds the capability of the human hand. Because of the stability and accuracy of the robotic arms, there is a decreased chance of surgical errors, which improves patient outcomes and reduces problems after surgery.[58]

ii. **Minimally Invasive:** Smaller incisions make robotic surgery less painful than traditional open surgery, which reduces the physical burden on patients.[59] Because there is less disruption of tissue and bleeding, this method usually results in less pain following surgery and lowers the danger of infection that comes with larger incisions. As a result, patients can return to their regular activities sooner since they have shorter hospital stays, quicker healing times, and less scars. Furthermore, because robotic surgery is minimally invasive, there is less need for postoperative care, which improves patient outcomes and lowers healthcare costs.[60] During surgery, blood loss can be considerably decreased due to the precise control that robotic equipment provides. This decrease in blood loss is essential for lowering the risks and necessity for blood transfusions, it improves surgical outcomes and makes the procedure safer.[61]

iii. **Minimal Human Error:** Robots may significantly reduce the risk of human error in surgical procedures because they don't get tired like human surgeons do. A surgeon's ability to concentrate might be affected by

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[55] ibid.
[56] van der Meijden and Schijven (n 41).
[57] Reddy and others (n 10).
[58] ibid.
[59]Michael W Nestor, Richard L Wilson, and Philosophy Documentation Center, 'An Anticipatory Ethical Analysis of Robotic Assisted Surgery': (2019) 38 Business and Professional Ethics Journal 17.
[60] 'Revolutionising Healthcare: The Advancements and Future of Robotic Surgery' <https://openmedscience.com/revolutionising-healthcare-the-advancements-and-future-of-robotic-surgery/> accessed 21 March 2024.
[61] Reddy and others (n 10).

fatigue, particularly during long procedures, which can result in serious performance and judgment errors. Unlike humans, however, robots are constantly stable, accurate, and fatigue-resistant, meaning that they can work for longer periods of time without losing functionality. Because they greatly lower the chance of error and increase the likelihood of a successful surgical outcome, robots become a viable substitute for human surgeons.[62]

iv. **Improved Access:** Robotic surgery increases the capabilities of doctors by enabling them to do procedures in narrow areas of the human body that would be difficult or impossible to access with traditional devices. The articulated instruments of robotic systems can perform complex movements and reach hard-to-reach areas, enhancing the surgeon's ability to treat complex problems successfully. By expanding the variety of treatments that can be performed minimally invasively, robotic surgery improves surgical outcomes and lowers patient trauma by offering new options for treating problems that previously needed more invasive approaches. Among the many advantages of robotic surgery are its improved access to challenging anatomical areas, decreased invasiveness, and enhanced precision. These advantages demonstrate how groundbreaking robotic surgery is in relation to modern surgical techniques. These benefits enhance surgical outcomes and speed patients' recovery, making this a noteworthy development in the field of surgery. As technology advances and the advantages of robotic surgery are further developed, the future of this procedure seems more promising in terms of safety, efficacy, and accessibility for patients worldwide. [63]

v. **Improved visualization:** An advanced High Definition (hereinafter, HD) equipment with telescopic camera shows the surgery region in high quality and at a magnified size. Additionally, the image can be viewed in three dimensions better than the human eye can.[64] It can be seen in three dimensions, magnified ten times, and moved in a full 360 degrees.[65]

vi. **Reduced risks of infection**: Because robotic surgery uses a minimally invasive technique with smaller incisions and softer tissue manipulation, there is a lower chance of infection following surgery. Smaller incisions reduce the possibility of contamination by minimizing the exposure of internal tissues to outside pollutants. In difficult operations, when infection might result in serious consequences, lower infection rates are especially important.[66]

vii. **Reduced complications:** Less preoperative and postoperative complications are a result of the accuracy of robotic tools and improved visibility offered by high-definition 3D imaging. Tissue manipulation by surgeons can be done with extreme precision and control, which lowers the possibility of bleeding or accidental injury. With more precise surgical techniques made possible by improved visualization, there is less chance of complications during the process, which enhances patient safety.[67]It helps surgeons to make safer and better surgical choices.[68]

viii. **Less postoperative pain**: Compared to open surgery, robotic surgery frequently results in less postoperative discomfort due to its smaller incisions and reduced tissue stress. Patients recover more quickly and require less pain medication when they are less uncomfortable. Higher levels of satisfaction and an improved patient experience are a result of this improved postoperative comfort.[69]

[62] Viswam (n 20).
[63] 'Revolutionising Healthcare: The Advancements and Future of Robotic Surgery' (n 62).
[64] 'Robotic Surgery' (*Cleveland Clinic*) <https://my.clevelandclinic.org/health/treatments/22178-robotic-surgery>.
[65] 'Apollo Robotic Surgery' (n 33).
[66] Reddy and others (n 10).
[67] ibid.
[68]Sinduja Jane, 'How Tech Shrinks Stress in Surgeons' *Indian Express* (8 May 2024).
[69] ibid.

1.3.2 Disadvantages of Robotic Surgery

These systems have a number of drawbacks, including the following:

Because robotic surgery is a relatively new technology, its applications and effectiveness are still being studied. In order to optimize the use of robotic arms and increase production, many processes will also need to be modified. [70] The cost is another factor, these devices cost a million dollars per, which is almost out of reach for many people. It is just unclear if these technologies will become more or less expensive in the future. Some think that as technology advances and more knowledge is gathered about robotic systems, the cost will decrease.[71] Some people think that the addition of technology like haptics, quicker processing, and more complex and powerful software will make these systems more expensive. Concerns also surface about how often and how much system updates occur.? How often and how much will it cost for hospitals and other healthcare facilities to make these upgrades? [72][73]

The size of these systems is another drawback. Both systems have comparatively large robot arms and heavy footprints. This is a significant drawback in the already packed operating rooms of today. The surgical team and the robot might find it challenging to fit within the operating area.[74][75] Some claim that reducing the size of the robotic arms and instruments will solve the issues arising from their present size. Some others think that the additional space needed for robotic surgical systems will lead to the need for larger operating rooms with several platforms and wall attachments. These robots are very expensive because of the area they require and their high costs.[76]

Tactile sensation for the surgeons will be reduced.[77] With the advancement of technology, the majority of the current constraints should be eliminated. It will take time to determine whether the investment in these technologies is beneficial. If expenses continue to rise and standard methods don't result in lower total costs, it's unlikely that robots would find a permanent place in every operating room and be utilized for regular surgeries.[78]

1.3.3 Cost Considerations in Robotic Surgery

Robotic surgeries hold great promise for the future, offering numerous advantages over traditional non-robotic procedures. These include the ability to transmit virtual data, greater precision and spatial accuracy, increased flexibility, faster movement, and fatigue-free operation, ensuring steady and consistent motions. These advancements enable less invasive surgical techniques, which can lead to reduced blood loss, shorter postoperative recovery times, lower pain and medication use, decreased infection risk, minimal scarring, and shorter hospital stays.

However, these benefits come with significant cost considerations.The initial investment in robotic surgery systems is substantial, with high costs related to purchasing, maintaining, and training for these advanced devices.While the long-term benefits, such as shorter hospital stays and faster patient recovery, may help offset these costs, it is essential to carefully balance these advantages against the financial impact on both healthcare providers and patients.[79]

Improving patient outcomes is the ultimate aim of each of these parts.[80] Furthermore, patients can resume regular activities and return to work sooner because to robotic surgery's faster recovery. In addition to helping people financially by lowering the number of days they must miss from work, this also lessens the need for temporary

[70] Anthony R Lanfranco and others, 'Robotic Surgery: A Current Perspective' (2004) 239 Annals of Surgery 14.
[71] Victor B Kim and others, 'Early Experience with Telemanipulative Robot-Assisted Laparoscopic Cholecystectomy Using da Vinci': (2002) 12 Surgical Laparoscopy, Endoscopy & Percutaneous Techniques 33.
[72] Lanfranco and others (n 71).
[73] Nestor, Wilson, and Philosophy Documentation Center (n 61).
[74] ibid.
[75] Anthony R Lanfranco and others, 'Robotic Surgery: A Current Perspective' (2004) 239 Annals of Surgery 14.
[76] Lanfranco and others (n 71).
[77] Nestor, Wilson, and Philosophy Documentation Center (n 61).
[78] Lanfranco and others (n 71).
[79] Nestor, Wilson, and Philosophy Documentation Center (n 61).
[80] Pai and others (n 3).

disability payments, which lowers indirect costs associated with lost productivity. Recoveries that are shorter can have an important impact on patients' capacity to return to their productive roles more quickly, highlighting the financial benefit of robotic surgery in enabling a quicker recovery and return to normal life.[81]

Some viewpoints, however, claim that robotic surgery is expensive and that there is insufficient acceptance of its advantages over traditional surgery. As a result, it is still thought that the field remains in its infancy.[82] The hospital and operating room components of the expenses were divided into separate categories. A group of experts examined the fixed and variable costs associated with each type of procedure and discovered that an open surgery costs $14,608 and a robotic procedure costs $16,248, respectively. Considering the fact that robotic surgery requires a shorter hospital stay, the cost is still $1640 greater than open surgery.[83]

On the other side the introduction of innovative machines, like the da Vinci® surgical robot, is influenced by the real and growing concern over costs in healthcare. To compare the exact costs of laparoscopic procedures performed with and without a robot, the equipment costs only make up a small portion of the overall medical costs. The direct expenses of robot-assisted surgery were 11.9% less than those of open surgery. The primary source of this cost discrepancy was the variation in hospital stays between patients receiving open vs. robot-assisted surgery. Whereas accommodation and board charges had the biggest impact on open surgery costs, maintenance fees and equipment expenses are the main drivers of robotic surgery costs. The overall cost of open surgery was less when estimates of the indirect expenses of purchasing and maintaining robots were taken into account. Complication rates and follow-up times did not differ.[84]

The main issue is that while some private health insurance companies cover the extra expenses of robotic instruments, others do not. However, as the technology gets more widely used and established, the cost will eventually decrease. Robotic surgical systems are currently on the market. More competition should lead to even lower costs, which will make robotic surgery more accessible and widely used.[85]

1.3.4 Surgeon Experience and Training

i. **Improved surgical skills:** Surgeons can become more comfortable with robotic equipment, enabling them to do complicated surgeries with more accuracy. The flexibility and simple operation of surgical robots enable surgeons to better develop their skills and handle difficult cases. Modified instrument control and high-definition 3D vision enhance surgical results, which in turn benefit patients by lowering the likelihood of complications and postoperative problems.[86] Constant robotic surgery practice and expertise enable surgeons to deliver excellent, minimally invasive care in a variety of specializations.[87]

ii. **Reduced physical strain:** The use of robotic surgery reduces the physical strain on surgeons during surgical procedures. Compared to traditional surgery, when surgeons frequently do physically demanding procedures for a longer period of time, robotic surgeons perform their operations while seated at a console. This ecological benefit lowers the possibility of weariness and musculoskeletal injuries, which benefits surgical teams' long-term health. Surgeons' overall job satisfaction and longevity are increased when they are able to perform complex procedures with greater comfort and precision.[88]

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[81] Reddy and others (n 10).
[82] 'Top 8 Robotic Surgery Companies in the United States' (n 22).
[83] Nestor, Wilson, and Philosophy Documentation Center (n 61).
[84] Courtney K Rowe and others, 'A Comparative Direct Cost Analysis of Pediatric Urologic Robot-Assisted Laparoscopic Surgery Versus Open Surgery: Could Robot-Assisted Surgery Be Less Expensive?' (2012) 26 Journal of Endourology 871.
[85] Viswam (n 20).
[86]Bishoy Morris, 'Robotic Surgery: Applications, Limitations, and Impact on Surgical Education' (2005) 7 MedGenMed: Medscape General Medicine 72.
[87] Reddy and others (n 10).
[88] Reddy and others (n 10).

iii. **Structured training:** Surgeons interested in using robotic surgery techniques can easily access extensive training programs, which are designed to guarantee both safety and competence. These structured programs provide opportunities for mentorship, as well as practical training and simulation-based exercises. Trainee surgeons can acquire the abilities and know-how needed to operate robotic devices safely and successfully. Additionally, ethical and patient safety concerns are emphasized in training programs, guaranteeing that surgeons are equipped to deliver the best possible care to their patients. The availability of structured training programs contributes to the development of a professional and competent workforce of robotic surgeons as the practice of robotic surgery becomes more common.[89]

1.4 FUTURE OF ROBOTIC SURGERY

Currently, robotic surgery is increasingly common globally, with expanding adoption due to its benefits in precision, minimally invasive procedures, and improving patient outcomes.[90]Currently, more than 7,500 da Vinci systems are used in 70 countries, and until 2022, more than 12 million procedures will be carried out globally with da Vinci systems. [91] The field of robotic surgery is developing quickly, overcoming challenges and raising new issues at the same time. Improvements remain even in the face of ongoing issues with national licensing for tele surgeons, credentialing, training requirements, and malpractice liability. Robotics has the potential to bring surgery into the digital era by improving existing methods and extending available treatments. Robotic systems are positioned to go above human constraints through enhanced precision and capabilities, which will potentially allow for the execution of surgical procedures beyond the scope of what is currently possible for humans. Even with all of the unknowns, the development of robotic surgery points to a revolutionary impact on healthcare that will improve patient outcomes and open the door for future innovative surgical techniques.[92]

India witnessed an incredible growth in robotic surgery throughout the subsequent ten years. As of July 2019, our nation had 66 facilities and 71 robotic installations, housing almost 500 skilled robotic surgeons. Over 12,800 surgeries have been carried out in the past 12 years with robotic help. As more robotic surgeons receive training and as other surgical specialties use this platform more often, the numbers should rise.[93]

Nonetheless, the surgical sector has been utilizing these new technologies, emphasizing the application of contemporary robotic systems made up of a motor device—which controls the movement of the camera and a visual device, which controls the movement of surgical tools. In certain instances, a spoken command system is available to enable the surgeon to direct the equipment. It is important to remember that, in the near future, the surgeon will play a more significant role in providing medical decisions, controlling robotic devices, and carrying out the treatment in a manner that offers the suggested surgical correction. Therefore, regardless of the interface that stands between a surgeon and a patient, the surgeon's hand will always be his most valuable tool.

CONCLUSION

In conclusion, robotic surgery has the potential to revolutionize the medical field by bringing about surgical accuracy, patient outcomes, and recovery periods. Throughout its development, robotic surgery has transformed medical practice by empowering physicians to carry out complex procedures using less invasive methods and

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[89] ibid.
[90] Bruna Bottura and others, 'Surgeon Experience, Robotic Perioperative Outcomes, and Complications in Gynecology' (2022) 68 Revista Da Associacao Medica Brasileira (1992) 1514.
[91] 'We Believe Minimally Invasive Care Is Life-Enhancing Care' <https://www.intuitive.com/en-us/about-us/company> accessed 26 March 2024.
[92] Lanfranco and others (n 76).
[93] Bora and others (n 21).

increased accuracy. The history of robotic surgery is one of technology innovation and human creativity, from its early days to its widespread use in hospitals across the world. By facilitating complex operations and movements that would be difficult using traditional methods, robotic surgery improves surgical precision. It makes use of cutting-edge features including wrist-mounted equipment and three-dimensional imaging, which eventually improve patient outcomes and comfort.

When the da Vinci surgical system was developed in the 1980s, it marked the beginning of a new era in surgical care and the development of robotic surgery. Since then, the discipline has advanced due to developments in robotic technology, which have expanded its applicability across a wide spectrum of surgical specialties. Today, patients have access to safer, more effective treatment options through the development of robotic surgery, which includes treatments in urology, gynecology, general surgery, and other fields.

Comparing robotic surgery to traditional surgical methods is a crucial step in understanding its significance. Although open surgery is still an important component of medical practice, robotic surgery has several benefits, especially because it is less invasive. Small incisions and accurate robotic arms operated by surgeons at a console are used in robotic surgery as opposed to extensive incisions and extended recovery periods required in conventional surgery. Patients benefit from less trauma, less blood loss, shorter hospital stays, and quicker recovery due to this minimally invasive procedure.

Robotic surgery offers revolutionary advantages to both patients and surgeons, resulting in an important change in the delivery of healthcare. With the continuous advancement of technology and the increasing ability of robotic systems, the field of surgery has countless opportunities for innovation and advancement. Healthcare industry can be continually transformed and patients can be given the best care possible by securing the potential presented by robotic surgery while tackling its ethical and legal issues.