



An Overview of Robotic Surgery: Past, Present, Future

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Abstract

This paper explores the multifaceted world of robotic surgery, by tracing its origins centuries ago through early innovations and breakthroughs, to its current state, and future ambitions. We begin with a brief overview of the new field and its various applications and specialties. The advantages of robotic surgery are covered along with an analysis of issues, including the need for human involvement. The economic scope of robotic surgery is evaluated through a discussion of market valuation and contributions of companies. Finally, the current and possible use of artificial intelligence in carrying out procedures is explored.

Introduction to Robotics

The term “robot” was coined by writer Karel Čapek - in his 1920 play R.U.R - after the Czech word ‘robota’, which refers to forced labor (Timelin, n.d). Robots are automated machines that execute particular tasks with little to no human intervention and with speed and precision.. The idea of robots, although a more modern concept, dates back many centuries. In the 18th and 19th century, ideas of building robots came up in an attempt to automate mass industrial production. During the 20th century, the first digitally operated and programmable robot, the Unimate (da Vinci & Richards, n.d.) was invented in 1954, thus laying the foundations of the modern robotics industry.

Robots, which are quick, precise and inexhaustible in their work, are better suited to industries such as manufacturing, agriculture, construction, logistics and most importantly – the automotive industry (*Top 10 Industries Utilizing Robots and Robotics*, n.d.) because they require very repetitive, boring and sometimes risky work. (Jain, 2024)



Fig 1: Usage of robots in automobile production (*Robots in Automotive Manufacturing - Robotic Integration Blog*, n.d.)

Robotic Surgery

Introduction

Robotic surgery, also known as robot-assisted surgery, is an approach healthcare providers use for minimally invasive procedures. These surgeries are carried out using mechanical arms that are controlled by the surgeon and bear surgical instruments and a camera, enabling them to perform numerous complicated procedures with increased precision and control as compared to orthodox procedures. Often, it is performed through tiny incisions but may also be used in open surgeries. (*Robotic Surgery*, 2024)

The technology consists of three main parts: robotic arms that hold tiny instruments, a high-definition camera that provides enhanced, magnified, 3D views of the surgical area, and a surgical console where a surgeon controls the instruments and the camera's every move similar to how we operate joysticks on an arcade game. (*Robotic Surgery: What It Is, Examples, Benefits & Risks*, n.d.) A robotic surgery system typically consists of a camera-arm and mechanical arms attached with surgical instruments which are controlled by a surgeon sitting at the control center, or console, near the operating table. Thus, the surgeon can observe a magnified, high-definition, 3D view of the surgical site, and lead their assistants during the operation. (*Robotic Surgery*, 2024). A robotic surgery thus results in smaller incisions than what is typically required by a normal open surgery.

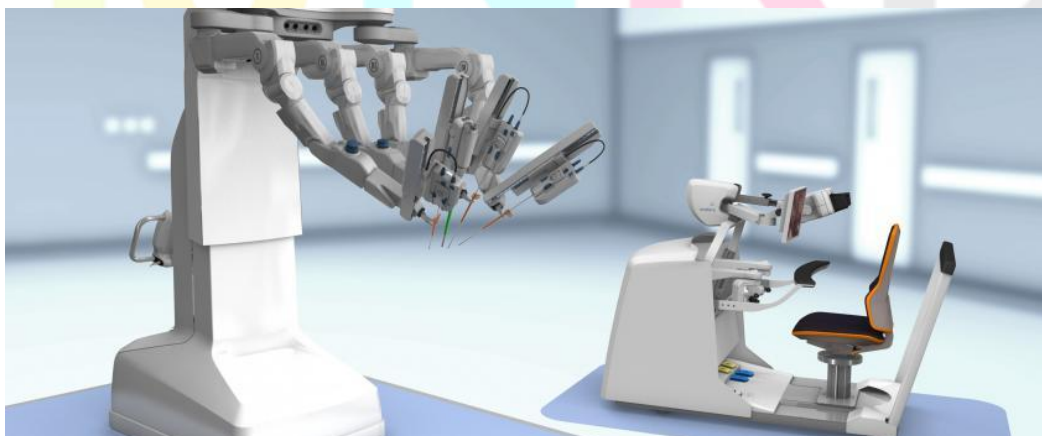


Fig 2: Da Vinci Surgical System (*Robot Surgery – 5 Interesting Facts About Da-Vinci Robotic Surgery - Blog | Delhi Apollo Hospitals*, 2022)

This provides the following advantages to the patient (*Benefits of Robotic Surgery*, n.d.) (*Robotic Surgery*, 2024):

- Faster and less painful recovery resulting in shorter hospital stays and quick return to regular activities
- Smaller incisions which result in lower risk and exposure to infections
- Reduced blood loss, transfusions, as well as discomfort
- Smaller and minimal scars
- Superior cancer control and nerve sparing (*Robotic Prostate Surgery - NYC*, n.d.)

Robotic surgery is not only beneficial to the patient but also to the surgeon: the robotic arms offer a greater range of motion, along with a camera that provides magnified, high-definition views, allowing them to operate inside the body using small incisions and instruments in ways that are far too out of reach for mere human hands.

The main cause of skepticism over robotic surgery is the fear of loss of jobs for surgeons. However, the robots do not actually replace surgeons, rather it is just one of many methods used to operate on patients.

History

While science fiction has always dramatized the use of robots, real experiments were started by NASA in the 1970s, especially in the field of telesurgery. However, it was the 1980s and the 1990s that saw rapid progress being made with PUMA 560 being used in a brain biopsy, PROBOT being used at the Imperial College, London during a transurethral prostate surgery and ROBODOC to prepare for femur replacements. (*The History of Robot-Assisted Surgery*, n.d.) A major milestone occurred in 2001 when Dr. Jacques Marescaux and Dr. Michael Gagner performed gallbladder surgery all the way from New York for a patient in France. This proved the viability of tele surgery.

There have been several manufacturers of initial equipment, like the Zeus system manufactured by Computer Motion and daVinci platform by Intuitive Surgical, but due to mergers and acquisitions, the industry consolidated on the daVinci platform. We are currently in the 4th generation of the daVinci platform based robotic surgery equipment.

Specialties Using Robotic Surgery

Robotic surgery can be applied across various surgical specialties, but its main application will be in areas where the organs are hard to reach and hence needed a significantly big open surgery. Examples of robotic surgery include (*Robotic Surgery: What It Is, Examples, Benefits & Risks*, n.d.), (*Robotic Surgery Specialties | Surgical Services*, n.d.)

- Appendectomy.
- Colectomy.
- Gallbladder removal.
- Gastric bypass.
- Hernia repair.
- Hysterectomy.
- Mitral valve repair.
- Pancreatectomy.
- Cardiothoracic surgery
- Colorectal Surgery
- Gastrointestinal surgery
- Gynecologic surgery
- Neurological surgery
- Otolaryngologic surgery
- Urologic surgery

Manufacturers of Robotic Equipment

There are several manufacturers of robotic surgical equipment. Some of these are older companies that used to manufacture general medical equipment whereas others are pure play robotic surgical equipment manufacturers. Major manufacturers of robotic surgical equipment include:

Company Name	Headquarters	Year of Founding	Surgical Equipment	Specialization
Smith & Nephew	London, UK	1856	NAVIO Robotic Knee System	Orthopedic surgery (knee replacement)
Stryker	Kalamazoo, MI	1923	Mako Robotic Arm Assisted Surgery System	Orthopedic surgery (knee and hip replacement)
Zimmer	Warsaw, IN	1927	ROSA Knee Robot	Orthopedic surgery (knee replacement)
Siemens/Medtronic	Dublin, Ireland	1949	Hugo RAS Robotic Surgical System	General, gynecological, and urological surgery
BR Surgical	Jacksonville, FL	1948	Various surgical instruments and equipment	General surgery
Intuitive Surgical	Sunnyvale, CA	1995	da Vinci Surgical System	General, gynecological, urological, thoracic, and cardiac surgery
MAKO Surgical Corp.	Fort Lauderdale, FL	2000	MAKO Robotic Arm Assisted Surgery System	Orthopedic surgery (knee and hip replacement)
Mazor Robotics	Caesarea, Israel	2003	Mazor X Stealth Guidance System	Spine surgery
Globus Medical	Audubon, PA	2003	Excelsius GPS Robotic Navigation System	Spine surgery
Virtual Incision	Lincoln, NE	2007	VIRUS Robotic Surgical System	General surgery
Medrobotics Corporation	Raleigh, NC	2009	Flex Robotic Surgical System	Ear, nose, and throat surgery
Asensus Surgical	Minneapolis, MN	2009	Senhance Surgical Robotic System	General, gynecological, and urological surgery

Locus Robotics	Wilmington, MA	2013	LocusBots	Warehouse automation and logistics
CMR Surgical	Cambridge, UK	2014	Versius Robotic Surgical System	General, gynecological, and urological surgery
Medical Microinstruments, Inc.	Memphis, TN	2015	FLIP Robotic Surgical System	Ear, nose, and throat surgery
SoftBank Robotics Group Corp.	Tokyo, Japan	2015	Pepper, NAO	Service robotics and human-robot interaction
Galen Robotics, Inc.	Baltimore, MD	2016	Galen ES Robotic Surgical System	Microsurgery (ENT, neurosurgery, otolaryngology)
Auris Health, Inc.	Redwood City, CA	2016	Monarch Platform	Lung cancer surgery
PROCEPT BioRobotics	Redwood City, CA	2016	AquaBeam Robotic Prostate Ablation System	Urological surgery
THINK Surgical, Inc.	Fremont, CA	2011	TMINI Miniature Robotic System	Orthopedic surgery (knee replacement)
AiM Medical Robotics	San Jose, CA	2016	MRI-Compatible Surgical Robot	Neuro surgery
CMR Surgical	Cambridge, UK	2016	Versius	General surgery

In addition, there are several upcoming startups like Vicarious Surgical Inc., MedRobotics Inc., Verb Surgical Inc. etc. innovating in this field. What is interesting is that several of the established companies in the medical equipment field like Johnson & Johnson, GE etc are also investors in several startups. This is an indication of the potential for this market to grow. Some projections show the total market for robotic surgical equipment is expected to grow up to \$188 billion from the current \$78 billion.

Role of Surgeons in Robotic Surgery

It is assumed that once robotic surgery advances, surgeons will be eliminated from the surgery and machines will take over surgeries. However, that is a far-fetched fantasy. Surgery still continues to be performed by real surgeons and robotic equipment provides support to the surgeon. Robotic equipment doesn't think or make decisions on their own. We can think of robotic equipment as the next generation of a scalpel or an MRI or ultrasound equipment.

However, surgeons would need extensive training before they can perform robotic assisted surgery. This includes theoretical training on the capabilities of the equipment, simulator training, training to use the console, training on cadavers, training as an assistant to an experienced robotic surgeon before becoming certified to use the robotic

equipment independently in surgeries. In addition, since each vendor's equipment is different, surgeons would need to be trained on the exact vendor's equipment provided by the vendor.



Fig 3: Highly skilled surgeons operating robotic surgical equipment (Barten, 2023)

Legal and Ethical Issues

Several legal issues can arise out of use of robotic surgical equipment. Medical malpractice lawsuits involving robotic surgery equipment have grown over 250% in the past 7 years (*Medical Malpractice in Robotic Surgery: A Westlaw Database Analysis, 2022*).

Unlike a surgeon that is licensed to practice medicine by a board, there is no official licensing authority for certifying a surgeon on robotic medical equipment. Instead, they rely on training provided by the vendor to certify the surgeon. This leaves the surgeon or the hospital open to training deficiency lawsuits. Robotic surgical equipment also needs continuous maintenance and calibration. Failure to properly maintain records of those can lead to negligence lawsuits. Manufacturing defects must be properly reported and timely corrective action needs to be taken.

Apart from legal issues, there are ethical considerations as well. This includes ways to ascertain accountability when things don't go as planned. Another issue is that of equitable access. Given that robotic surgery tends to be more expensive, access to such surgeries aren't available to everyone. In addition, there are privacy and data security issues, with the patient information being stored in the surgical equipment systems. Informed consent of the patient by discussing various options, including traditional as well as robotic surgery w.r.t cost, risks must be sought.

Innovations in Robotic Surgery

Technology advancements are improving the ability of robotic surgery. Innovations in hardware and software helps achieve better outcomes in surgery.

Camera miniaturization is one important innovation that lets the surgeons access to parts that were hitherto unreachable. 3 dimensional HD vision improves the quality of images that allows better diagnosis.

Tremor filtering is another advanced technique (Pan, nd) that allows to eliminate the impact of hand tremors during robotic surgery.

Improvement in latency of response time reduces the response time of the surgeon to any observation or data.

Flexible arms that can move the snakes allows them to pass through orifices or blood vessels to be used for colonoscopies or bronchoscopies.

Improvement in haptic feedback allows the surgeons to feel the consistency of tissues without damaging them. This helps in preventing injuries during surgery.

Artificial Intelligence in Robotic Surgery

Artificial intelligence is a collection of multiple techniques that includes machine learning deep learning, Natural Language Processing, Generative AI.

Artificial intelligence can be enhanced to improve patient care in all facets of surgery (Guni, 2024). This includes

- Pre Operative
- Intra Operative
- Post Operative

Pre operative uses of AI include accurate diagnosis, screening, processing of patient information, and risk prediction. This involves processing patient records and EHR records and comparing them with a database of global patient data. Generative AI and Natural Language Processing can be used to enhance the training experience of surgeons.

Intra operative uses of AI includes using computer vision algorithms to identify anomalies with the camera images and video to provide guidance to the surgeon, and support augmented reality for telesurgery. A lot of work is needed to label existing images and video to be able to identify anomalies and is a current topic of research.

Post operative care uses of AI includes identifying complications of the surgery based on monitored parameters and test results, scheduling follow up appointments, and identifying post operative risks based on machine learning algorithms.

Since AI algorithms are very reliant on the training data used to train the models, care must be taken that a diverse set of patients (across geographies, social strata, dietary preferences, gender) is used to train the model. Otherwise, there is scope for misidentifying risks and issues.

Current State of Robotic Surgery

With the da Vinci system being introduced only around 20 years ago, it is reasonable to expect that robotics has not been completely involved in all surgeries yet.

An astounding 313 million surgeries are carried out each year (*What Is Da Vinci Robotic Surgery? A Complete Overview*, n.d.). Whereas a total of 11 million robotic surgeries since 2000 (*New Robotic Platforms in General*

Surgery: What's the Current Clinical Scenario?, 2023) gives an average of just 550,000 surgeries a year and 1506 surgeries per day, which constitutes an extremely small fraction of the total surgeries performed in hospitals.

Procedures that are commonly performed by robots include prostate surgery, hernia surgery, knee replacement surgery, gallbladder removal surgery and hysterectomy (Richmond University Medical Center, 2023). The former is automated the most, with 85% of radical prostatectomies (removal of some or all of the prostate) in the U.S being performed by robots (Schmidt, 2022), with the others following closely.

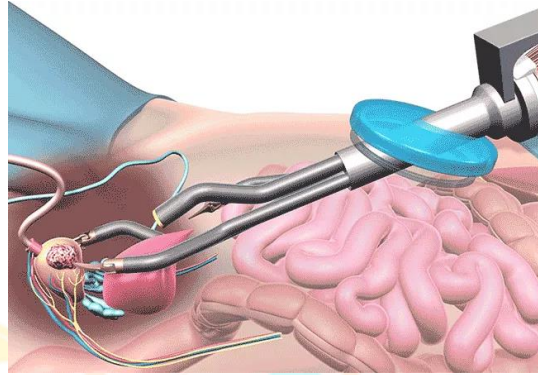


Fig 4: Prostate surgery using robotic equipment (*First Prostate Surgery Performed in U.S. Using Single Port SP Robot*, 2018)

Future of Robotic Surgery

As mentioned earlier, robotic surgery is a huge growing market. To enable widespread use of robotic surgery, it needs to be made more affordable. Human Machine interface (HMI) needs to be standardized so that surgeons can be trained across a wide variety of devices across vendors. The legal framework around robotic surgery needs to be clarified further to reduce liability for surgeons. Robotic surgery needs to be seen as an aid to surgeons rather than as a replacement. Even so, more and more functions of robotic surgery need to be made more autonomous to free up the time of medical staff. This will be facilitated with the use of Artificial Intelligence. Newer sensors, cameras, haptic feedback and more flexible and functional arms will enable surgeons to go beyond traditional surgery methods and evolve newer surgeries that were hitherto considered impossible to perform. With tele surgery, patient care can be extended to remote areas which will enable surgeons to expand their coverage to a larger geography.

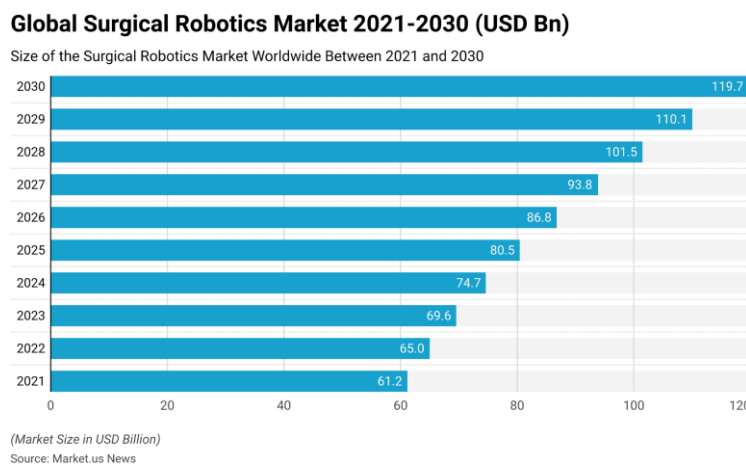


Fig 5: Projected global surgical robotics market size (*Robotic Surgery Statistics 2024 By - Procedures, Safety*, n.d.)

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