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The Journey of Robotic Technology in Plastic Surgery

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Abstract

Robotic technology is the latest step in the evolution of minimally invasive techniques. With its enhanced precision and visualization robotic surgery augments the capabilities of plastic surgeons. Robotic technology aids in achieving more precise interventions. This chapter provides an overview regarding the evolution of robotic surgery from its origin to present scenario with its technical details and its myriad of applications in medical sciences with focus on plastic surgery. The limitations and recent advances are also discussed.

Keywords: Robotic Technology; Plastic surgery; Minimal access surgery; Recent advances.

INTRODUCTION

A 'Robot' is defined as a computer controlled mechanical device equipped with sensors and actuators and is re-programmable. It may look like a human being and perform various complex acts (as walking or talking) of a human being, lacks human emotions, functions automatically, performs complicated often repetitive tasks guided by automatic controls. Robotic Surgery, computer assisted surgery and robotically assisted surgeries are synonym terms used for robotic systems to aid in surgical procedures. Robotics is the branch of mechanical engineering, electrical engineering, electronic engineering and computer science that deals with the design, construction, operation, and application of robots, as well as computer systems for their control, information processing and sensory feedback. Robotic surgery, or robot assisted surgery, allows doctors to perform many types of complex procedures with more precision, control and flexibility than is possible with conventional techniques. Robotic surgery is usually associated with minimally invasive surgical procedures performed through tiny incisions.[1]

HISTORY

In 1923, the play R.U.R. by Karel Čapek was opened in London and New York. In this play "R.U.R." meant for "Rossum's Universal Robots," a company formed by an English scientist named Rossum to manufacture human like machines called "robots" to do hard, boring jobs. Karel Čapek's play was popular, and soon the word 'robot' became a general term for machines that can perform the tasks of a person.[2] In 1954, George

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Devol, who is credited as father of robot, patented the first manipulator with playback memory. This event marked the beginning of the robotic age. His device was capable of point-to-point motion and was the forerunner of devices used by industry today. Minimally Invasive Surgery (MIS) or minimal access surgery (MAS) and laparoscopic surgery are "transitional" technology in the history of surgical evolution which lead to robotic surgery. In 1961, Joseph F. Engelberger formed a company called Unimation which began the commercial production of robots for industry. The first robot to assist in surgery was developed and used for the first time in Vancouver in 1983 and it was called the Arthrobot. Other related robotic devices developed at the same time included a surgical scrub nurse robot, which handed operative instruments on voice command, and a medical laboratory robotic arm. In 1985, a robot, the Unimation Puma 200, was used to place a needle for a brain biopsy using CT guidance.[3] In 1992, the PROBOT, developed at Imperial College London, was used to perform prostatic surgery. The ROBODOC from Integrated Surgical Systems (working closely with IBM) was introduced in 1992 to mill out precise fittings in the femur for hip replacement. Further development of robotic systems was carried out by Intuitive Surgical and SRI International with the introduction of the da Vinci Surgical System and Computer Motion with the AESOP and the ZEUS robotic surgical system. Examples of using ZEUS include a fallopian tube reconnection in July 1998, a beating heart coronary artery bypass graft in October 1999, and the Lindbergh Operation, which was a cholecystectomy performed remotely in September 2001. Initially the telesurgical robot was intended to facilitate remotely performed surgery in battlefield and other remote environments but it turned out to be more useful for minimally invasive on-site surgery. Examples of using da Vinci system include the first robotically assisted heart bypass in Germany in May 1998, and the first performed in United States in September 1999; and the first all-robotic assisted kidney transplant, performed in January 2009. In June 2008, the German Aerospace Centre (DLR) presented a robotic system for minimally invasive surgery, the MiroSurge.[4,5] In ophthalmic surgery, ocular robot 'The Microhand' is used for ocular microsurgical procedures by using it as micro-forceps to apply calibrated forces on ocular tissues.[6]

1989: Computer Motion a high tech medical device company was founded with a goal to revolutionize surgical practices and to improve patient lives.

1992: Robodoc introduced integrated surgical systems by for orthopaedic surgery, specifically for total hip arthroplasty.

December 1993: The AesopTM 1000, a robotic system used for holding an endoscopic camera in minimal invasive laparoscopic surgery was developed by computer motion and approved by the FDA.

1997: The da Vinci Surgical System manufactured by Intuitive Surgical Inc., became the first assisting surgical robot to receive FDA approval to help surgeons to perform laparoscopic surgery more easily.

1998: In the United States Dr. Frank Diamiano was the first to perform the procedure of reanastomosis of a fallopian tube using the Zeus system.

September 24, 1999: The world's first robotically-assisted closed chest beating heart cardiac bypass operation on 60-year-old dairy farmer John Penner using the Zeus system was performed by Dr. Boyd of London Health Sciences Centre's (LHSC) university.

March 13, 2000: Dr. Francois Laborde of L'Institut Mutualiste Montsouris Chiosy performed the first time paediatric cardiac procedures using Computer Motion's Zeus robotic assistance to perform seven fully endoscopic closures of the patent ductus arteriosus (PDA).

October 9, 2001: ZEUS Robotic Surgical System from Computer Motion received FDA regulatory clearance with the decision for U.S. surgeons to utilise a variety of instruments to perform a wide range of robotically assisted laparoscopic and thoracic procedures.

2001: First robot was procured in India by the Escort hospitals and was used for cardiac surgery.

July 7, 2004: FDA cleared the marketing of a robotic like system to assist in coronary artery by pass surgery enabling the surgeon to perform heart surgery while seated at a console with a computer and video monitor.

April 9, 2005: A laparoscopic right hepatectomy, removing approximately 60 percent of liver, and the tumour using the da Vinci Surgical System was successfully performed by Surgeons at the University of Illinois Medical Centre at Chicago.

2006: The first robotic program in Urology was started at AIIMS, New Delhi.

June 2008: German Aerospace Centre (DLR) presented a robotic system for minimally invasive surgery, the MicroSurge.

January 2009; First all robotic assisted kidney transplant was performed.[4,5]

INDICATIONS

Robotic surgery is not an option for everyone. In general, robotic surgery is being explored in almost all the branches of medicine for different indications (Table 1).[7]

Orthopedic Surgery	Neuro-Surgery	Gynecologic Surgery	Cardiothoracic Surgery	Urology	General Surgery	Plastic Surgery
Total hip arthroplasty	Complement image guided surgery	Tubal reanastomosis	Mammary artery harvest	Radical prostate ctomy	Cholecystec -tomy	Robotic Assisted Micro Surgery (RAMS)
Knee surgery	Radio Surgery	Hysterectomies	CABG	Ureter repair Nephrectomy	Nissen fundoplication	Transoral robotic surgery (TORS)
Spine surgery	–	Ovary resection	Mitral valve repair	–	Heller Myotomy	Transoral Robotic Cleft Surgery (TORCS)
–	–	Transluminal Endoscopic surgery	Video assisted thoracoscopic surgery (VATS)	–	Gastric bypass	Elevation of pharyngeal flaps
–	–	–	–	–	Adrenalectomy	Latissimus Dorsi (LD) and rectus abdominis muscle flap elevation
–	–	–	–	–	Bowel resection	Brachial Plexus surgery
–	–	–	–	–	Esophagectomy	–

CONTRAINDICATIONS

Number of indications of robotic surgery have increased in the last decade but there are contraindications for robotic surgery, few of which are as follows:[8,9]

Absolute contraindication

- Increased intracranial pressure (except in plastic surgery and ophthalmic surgery)

Relative contraindications

- Obesity (BMI greater than 30 kg/m^2), it distorts anatomy and complicates placement of the ports (except in plastic surgery and ophthalmic surgery)
- Intra-abdominal adhesive disease
- Cardiac disease
- Emphysema
- Chronic respiratory disease
- Glaucoma
- Stroke

BENEFITS

Robotic surgery makes minimally invasive surgery possible which has the following benefits:[8,9]

- Complications are fewer, such as surgical site infections.
- Pain, blood loss and need for blood transfusion is less.
- Recovery is quicker post-surgery.
- Scar is small and less noticeable.

In general, following benefits are noted with robotic surgery over conventional surgery:

- Good geometric accuracy is possible.
- Stable and untiring system.
- Can Scale motion
- Can use diverse sensors in control
- Can be sterilized
- System is resistant to radiation
- Three major advances aided by surgical robots have been remote surgery, minimally invasive surgery and unmanned surgery.

- As far as Robotic Assisted Micro Surgery (RAMS) is concerned, robot takes longer time for anastomosis but they perform high quality, tremor free precise microsurgery without any technological problem and intra-operative complications.

DRAWBACKS

Following is some of the drawbacks of robotic surgery over conventional surgery:[8, 9]

- Robotic surgery has Fulcrum effect- the instrument should be placed in the opposite direction from the desired target on the monitor to interact with the site of interest, hand eye coordination is therefore compromised.
- Restricted degrees of motion are present.
- It is difficult to judge properly.
- Inability to use Qualitative information.
- Haptic sensation is absent
- It is expensive
- It is a technology in flux
- More number of research and studies are required.
- Robotic surgery generally costs as much as $3,500 more than a conventional surgery. A single robot costs about $2 million.

COMPLICATIONS

Robotic surgery involves risk, some of which may be similar to those of conventional open surgery, such as risk of infection. Other complications which have been noted with robotic surgery are as follows:[8,9,10]

- Cardiac arrest robotic arm pressing against neck
- Myocardial infarction
- Subcutaneous emphysema
- Pulmonary edema
- Peripheral neuropathy
- Compartment syndrome
- Paradoxical cerebral air embolism
- Complications related to patient positioning
- Robotic malfunctioning

Application In Plastic Surgery

Various indications for which Robotics in plastic surgery has been explored are:

(1) Transoral Robotic Surgery (TORS) for head and neck reconstruction, allowing complex oropharyngeal reconstruction without dividing the lip or mandible.

(2) Robotic microvascular anastomoses, extending the capabilities of the human hand.

(3) Minimal access muscle harvest for an "incision less" harvest of both the latissimus dorsi and rectus muscles.[11-19]

(4) Robotic surgery has been applied in hair transplantation surgery using the ARTAS Robotic System which is a physician-controlled system that enables the improved, speedier harvesting of hair follicles for transplantation. The product combines an image-guided robotic arm and imaging features with a system that can identify and harvest individual follicular units to implement the follicular unit extraction (FUE) technique. ARTAS System has been granted 510(k) clearance by the FDA.

RECENT ADVANCES

In future robotic surgery has promising ways of accomplishing delicate medical procedures. Robotic surgery systems will be capable of functioning at greater distances allowing robotic surgery to be conducted with patients in a nearby “clean room,” reducing or eliminating intraoperative infection. It will be possible for next generation medical robotics and robotic surgery to conduct surgical prep work remotely as well. Advancements in replicating the tactile feel and sensation will give surgeon the feel of real world and advantage of precision. Giving surgeon the ability to control more than two arms will essentially allow the surgeon to become their own assistant.[20-21]

Newer colonoscopic surgical robots demonstrate improvements in four crucial areas: adjustable stiffness, detectability, bendability, and controllability. A miniature robotic system (“Endotics”) with inch worm like vacuum based mobility has been described, to enhance the accuracy of colonoscopic diagnosis and surgery. The NeoGuide colonoscopy system is an advanced soft robot that incorporates compliance, safe interaction with the body, actuation and sensing, greater dexterity and increased workspace.

The Minimally Invasive Neurosurgical Intracranial Robot (MINIR) is another newer robot used to remove brain tumours, based on a CTSM with SMA actuators. The AerOScope is an Israeli self-propelling colonoscope that uses carbon dioxide to push itself through the colon up to the cecum, without the need for external pushing.[22-23]

NOTES

Such advancements also bring natural orifice transluminal endoscopic surgery (NOTES) nearer, where surgery can be truly non-invasive, by helping to achieve greater stability of the instruments despite their flexibility, allow sufficient force to be applied for traction and large organ retraction, proper positioning of the instruments, greater dexterity and imaging quality.

Miniature In Vivo Robots

Miniature in vivo robots, developed by Virtual Incision and Centre for Advanced Surgical Technology (CAST), are a novel approach with the whole MIS surgical platform being inserted into the peritoneal cavity. These have two arms with multiple functionalities and several joints for unlimited flexibility.

Capsule Robots

The capsule robots are miniaturized endoscopes that can be used in many diagnostic tests, surgeries and for drug delivery. They can be manipulated via magnetic interactions, allowing for an untethered design with enormous freedom of movement, and are extremely small, causing less tissue damage and fast accessibility.

Microbots

Microbots, though far in the future, are a potential advancement which do not require any incision at all, but could be introduced into the circulation and transported to a specific destination.[24-26]

ROBOTIC SURGERY IN INDIA

Currently, the robotic surgery in India is in its infancy. Escort hospital in 2001 procured the first robot in Asia and used it for cardiac surgery. The first urology robotic programme was started at AIIMS, New Delhi in 2006. Other specialty where robotic system in India being used is orthopaedic spine surgery. There are currently 66 centres and 71 robotic installations as on July 2019, with more than 500 trained robotic surgeons in our country. More than 12,800 surgeries have been performed with robotic assistance in these 12 years. The numbers are expected to increase as more robotic surgeons get trained and other surgical specialties increasingly utilizing this platform.

Financial factor is the major reason why robotic surgery in India has not progressed at a faster rate. The only way is to develop indigenous surgical robots. Department of biomedical engineering at the Indian Institute of Technology have made some headway in developing Indian prototype. Soon, India will be part of robotic revolution across different specialties to lead the way and make maximum use of robotic surgery.[27-31]

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