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Robotic Surgical Systems—A Review

Apoorva Chaudhary[1], Dinesh K. Atal[2] and Sanjeev Kumar[3]

[1,2]Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Haryana
[3]Central Scientific Instruments Organization (CSIR-CSIO), Chandigarh

Abstract

Robotic surgery is a type of surgery where doctor performs the operation on the patient by controlling the arms of the robotic system. These robotic arms mimic the surgeon's hand and scales down the movement hence allowing the surgeon to easily make precise and small cuts. Robotic surgery has been a revolutionary step in the improvement of surgical procedures as it is enhancing surgery through improved precision, stability, and dexterity. The use of robotics in medical procedures has become common place in the past decade as medical robotics includes a number of devices used for surgery, rehabilitation therapy, assisting people with disabilities and prosthetics. Due to the wide acceptance of surgical robots, the need to provide smaller, more efficient and less expensive equipment is driving researchers to achieve great heights. Surgical robots have been successfully implemented in several hospitals around the globe and have received world-wide acceptance. With advancements in technology, accuracy and proficiency is being achieved by various surgical systems and the current study reviews the latest robotic surgical technologies.

Keywords: Surgical robots, medical robotics, surgical advances, robotic surgery, minimally invasive surgeries.

1. Introduction

Robotic surgery is a proliferating new technology that is taking the surgical profession by storm. Surgical robots provide surgeons with high precision and dexterity, necessary to perform the complex, minimally invasive surgical (MIS) procedures. “Minimally invasive” means that instead of operating on patients through large incisions miniaturized surgical instruments that fit through a series of quarter-inch incisions are used[1]. In the case of robot-assisted minimally-invasive surgery, instead of directly moving the instruments, the surgeon uses different methods to control the instruments; either a direct tele manipulator or through computer control. Surgical Robots also increase the scope and effectiveness of MIS as key advantages of robotic surgery include the requirement of small incision, high accuracy and ability to repeat identical motions, less pain, less scarring, less bleeding, lower risk of infection, shorter hospital stays, quicker recovery time and return to normal activities, 3D vision, motion scaling, fluid movement, wrist articulation capability, remote sensing technology, tremor filtering, ergonomically intuitive sensing, 25 times more magnification, multiple instruments entrance system, haptic feedback and tele-surgery with tele-proctoring and it also has some limitations including absence of tactile or haptic information, surgeon's judgment, high cost and not being able to use qualitative information[2].

2. Robotic Surgical Systems

Surgical Robots have very high costs but have proven to be profitable for the society. There are three main categories when it comes to robotic surgical systems including:

2.1 Supervisory-Controlled Systems

Supervisory-controlled systems are the most automated but can't perform surgery without any human guidance. Surgeons must do extensive prep work with surgery patients before the robot can operate. The drawbacks of these systems are that once the instructions have been input and the sequence initiated, there is no place for error as there is no way to make any adjustments to the procedure in real time. These types of surgeries are common in hip and knee replacements [3,4].

2.2 Tele surgical Systems

Tele surgery is also known as remote surgery in which the surgeon manipulates the robotic arms during the procedure rather than allowing the robotic arms to work from a predetermined program. Surgical tasks are directly performed by a robotic system which is controlled by the surgeon at a remote location.

2.3 Shared Control Systems

Shared-control robotic systems aid surgeons during surgery, but the human does most of the work. It is a type of robotic surgery in which the robot performs the entire procedure using a program preset by the surgeon. The robotic system monitors the surgeon's performance and provides stability and support through **active constraint.** Active constraint is a concept that relies on defining regions on a patient as one of four possibilities: **safe, close, boundary or forbidden.** Shared Control systems are often used in neurosurgery and orthopedic surgery [3].

3. Recent Advancements In Technology

3.1 The Socrates Robotic Telecollaboration System

The Socrates system allows the surgeon in the remote area to interact with the operative surgeon located in any other area. This system allows viewing video images generated by an overhead camera or endoscope being used at the operative site. In February, 2001; first robotic surgery using the Socrates System was performed.

Applications: With the use of SOCRATES, new definitions have evolved.

Telementoring-the use of this technology for teaching by an expert surgeon at the remote area to the second surgeon in an operating room via video-conferencing technology.

Telesurgery-the surgeon performs the operation sitting on a console from a remote location and the location of the console can be within a few feet or away from the operating site.

Telestration-Surgeon puts marks on a drawing tablet to virtually illustrate on the local surgeon's video screen and this can be used to highlight the area of interest; tumor mass, for example[5].

3.2 Sofie Surgical Robot

Surgeon's Operating Force-Feedback Interface Eindhoven (Sofie) developed by Eindhoven University of Technology is the first surgical robot which works on the force-feedback mechanism allowing the surgeons to experience physical feedback. Sofie can alter the resistance of the surgical controls based on the amount of force being exerted on the patient’s tissues, which helps surgeons keep track of the amount of pressure being applied on the patient’s organs. This also works on the concept of master-slave in which master and slave are completely separated from each other and the communication takes place through the data cables. Sofie is also compact than most surgical robots, and can be mounted on the operating table instead of the floor and hence makes the task of approaching organs from different directions easier[6].

3.4 iDrive Intelligent Power Unit

The **iDrive** by Power Medical Interventions (PMI) is a detachable intelligent surgical instrument and iConsole device which is designed to support a variety of minimally invasive procedures by offering surgeons broad range of cutting and stapling configurations combined with increased flexibility, precision and access. The iDrive is a hand-held, computer-controlled power unit to which PMI's intelligent surgical instruments can be attached and this innovation allows these intelligent surgical units to be driven by a single power unit which further leads to reduced cost; less than half of the current cost. Hence, iDrive is easy to use, cost-effective, reusable and less wasteful, potentially leading to savings for health centers [7].

The **iConsole** is a wireless device that communicates directly with the iDrive during surgical procedures to output specific auditory and visual reference information via its speaker and liquid crystal display. iConsole allows surgeon to make real-time, critical decisions that may lead to an improved patient outcome

Applications include resection and transection of tissue and to create anastomoses between structures [3].

3.5 The Stealth Station

The Stealth Station by Medtronic Surgical Navigation Technologies is a 3-D imaging system allowing the surgeons to navigate through the body. It combines images from variety of sources including X-Ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Ultrasound. Due to the combination of these different techniques, more precise 3-D images are acquired allowing the surgeon to focus on exact desired location, simultaneously providing the real-time images throughout the surgery [8]. *Advantages* include less pain, less scarring, reduced recovery time and reduced radiation exposure.

Applications include tumor biopsy, tumor resection, total knee and hip transplant, Functional endoscopic sinus surgery and screw placement through the spine.

3.6 Spider Surgical System

The Spider Surgical System is a flexible laparoscopic platform for performing minimally invasive surgery allowing multiple instruments to be used through one incision. Eliminating the earlier crossed arm movements, Spider allows a single surgeon to operate from true right and left instrument manipulation. The system allows the surgeon to perform different procedures using a combination of flexible and common laparoscopic instruments and is a single operator platform allowing triangulation to be achieved via single site access. *Advantages* include less scarring with potential for limited post-operative pain and a faster recovery time [9].

3.7 DA Vinci Single-Site Surgery

Intuitive's da Vinci Single-Site Surgery enables surgeons to operate through a small incision in the patient’s belly button in order to remove the gallbladder or uterus. It is compatible with the da Vinci Si Surgical System. Instruments and camera cross within the single-site port and use remote center technology to avoid collisions of cannula, arm interferences and port-site movement. The da Vinci system software automatically detects and re- associates the user’s hands with the instrument tips to create Intuitive movement through crossed cannulae. Major advantage of these system is virtually scarless surgery [10].

3.8 New da Vinci Sp Single Port Minimally Invasive Robotic System

Intuitive's New da Vinci Sp single port robot assisted surgical system delivers a 3D high-definition camera and three fully articulating instruments through its 25 mm cannula. The EndoWrist Sp Instruments used by the system have two more degrees of freedom than the da Vinci Single-Site instruments allowing substantially more control for the surgeon [10].

Applications: The system is initially indicated for urologic minimally invasive procedures that are already performed via a single incision [11].

3.9 The da Vinci Si system

The *da Vinci Si* System is built on the core technology at the heart of the existing *da Vinci* and *da Vinci S* Systems and provide advanced 3D HD visualization with up to 10x magnification and an immersive view of the operative field. These systems also enclose Endo wrist instrumentation with dexterity and range of motion far greater than the human hand. The presence of Intuitive Motion technology, imitates the experience of open surgery by preserving natural eye-hand-instrument alignment and intuitive instrument control. The *da Vinci Si* Surgical System provides Control and Comfort to the surgeon, OR Efficiency and Integrated technology & data [10].

Year	Surgical system	Manufacturer	Use
2001	Socrates Robotic Telecollaboration System	Developed by Computer Vision	Used for sharing control of AESOP 3000 from different locations
2001	Zues Surgical System	Developed by Computer Motion	Used for robotic- assisted thoracic and laparoscopic surgeries
2004	Trans-rectal Ultrasound (TRUS) Prostate Robotic System	Developed by John Hopkins University	Used for trans-rectal ultrasound guided biopsy of prostate
2005	The Raven I	Developed by University Of Washington	Used for open-surgery and MIS
2006	TRUS-Guided Brachy-therapy	Developed by John Hopkins University	Used in Trans-rectal ultrasound guided brachytherapy
2007	NeuroArm	Developed by University of Calgary and MacDonald Dettwiler and Associates	Used in neurosurgery for both biopsy and microsurgery
2009	Robotic Doppler Micro Probe	Developed by Vascular Technology	Used for vascular identification in robotic microsurgical procedures
2009	iDrive Intelligent Power Unit	Developed by Power Medical Interventions	Used for resecting and transecting tissue as well as for creating anastomoses between structures
2010	SOFIE "Surgeon's Operating Force-feedback Eindhoven" Surgical Robot	Developed by Eindhoven University of Technology	1st surgical robot based on force feedback
2012	The Raven II	Developed by University Of Washington and UC Santa Cruz	Open- Source surgery robot

2012	Amadeus Robotic Surgical System	Developed by Titan Medical Inc	Used for laparoscopic surgery

Fig. 1: Major Surgical Robots (Timeline)

4. Conclusion
Robotic surgery has developed over the past 10 years and we have reached to an extent where the surgical procedure can be performed without being directly visualized and touched. Robotic surgery has developed and enhanced several surgical techniques in specialties such as urology, general surgery, and gynecology, ophthalmology but still much is in the horizon to study and develop in robotic surgery but the results obtained are encouraging and it seems to be just a matter of time until robotic surgery becomes the new standard of treatment in a significant amount of surgical procedures establishing new standards of treatment and demonstrating that it is here to stay and evolve.

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