A Review on Robotics in Surgery

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***Abstract*—The field of surgery is entering a time of great change, spurred on by the remarkable recent advances in surgical and computer technology. Only recently have Robotics systems made their way into the operating rooms as dexterity enhancing surgical assistance and surgical planners in answer to surgeons' demands for ways to overcome the surgical limitations of minimally invasive laparoscopic surgery. Robots in the field of surgery have dramatically changed the procedures for the better. The most significant advantage to Robotic Surgery to the patient is the decrease in pain and scaring. The smallness of incisions also causes many other advantages that make Robotic Surgery worth the risk. Besides the obvious rewards to the patient, Robotic Surgery is also very advantageous to the Surgeon and Hospital.**

Keywords*— FDA - U.S. Food and Drug Administration, AESOP - Automated Endoscopic System for Optimal Positioning, SBIR - Small Business Innovation Research, CABG – Coronary artery bypass graft

I. INTRODUCTION

Just as computers revolutionized the latter half of the 20th century, the field of robotics has the potential to equally alter how we live in the 21st century. We've already seen how robots have changed the manufacturing of cars and other consumer goods by streamlining and speeding up the assembly line. We even have robotic lawn mowers and robotic pets. And robots have enabled us to see places that humans are not yet able to visit, such as other planets and the depths of the ocean. In the coming decades, we may see robots that have artificial intelligence. Some, like Honda's ASIMO[1] (Fig 1.1) robot, will resemble the human form.

Fig 1

They may eventually become self-aware and conscious, and be able to do anything that a human can. When we talk about robots doing the tasks of humans, we often talk about the future, but robotic surgery is already a reality.

Doctors around the world are using sophisticated robots to perform surgical procedures on patients. While robotic surgery systems are still relatively uncommon, several hospitals around the world have bought robotic surgical systems. Three major advances aided by surgical robots have been remote surgery, minimally invasive surgery and unmanned surgery.

II. BRIEF HISTORY

In 1985 a robot, the PUMA560 was used to place a needle for a brain biopsy using CT guidance.

In 1988, the PROBOT, developed at Imperial College London, was used to perform prostatic surgery.

The ROBODOC from Integrated Surgical Systems 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 with the introduction of the DA Vinci Surgical System and Computer Motion with the AESOP and the ZEUS[2] robotic surgical system.

In 1997 a reconnection of the fallopian tubes operation was performed successfully in Cleveland using ZEUS[2].

In May 1998, Dr. Friedrich-Wilhelm Mohr using the DA Vinci surgical robot performed the first robotically assisted heart bypass at the Leipzig Heart Centre in Germany.

In October 1999 the world's first surgical robotics beating heart coronary artery bypass graft (CABG) was performed in Canada using the ZEUS[2] surgical robot.

The first unmanned robotic surgery took place in May 2006 in Italy.

III. CLASSIFICATION

Not all surgical robots are equal. There are three different kinds of robotic surgery systems: supervisory-controlled systems, telesurgical systems and shared-control systems. The main difference between each system is how involved a human surgeon must be when performing a surgical procedure.

On one end of the spectrum, robots perform surgical techniques without the direct intervention of a surgeon. On the other end, doctors perform surgery with the assistance of a robot, but the doctor is doing most of the work.

A. Supervisory Controlled Robotic Surgery System

Of the three kinds of robotic surgery, supervisory-controlled systems are the most automated. But that doesn't mean these robots can perform surgery without any human guidance. In fact, surgeons must do extensive prep work with surgery patients before the robot can operate.

That's because supervisory-controlled systems follow a specific set of instructions when performing a surgery. The human surgeon must input data into the robot, which then initiates series of controlled motions and completes the surgery. There's no room for error -- these robots can't make adjustments in real time if something goes wrong. Surgeons must watch over the robot's actions and be ready to intervene if something doesn't go as planned.

The reason surgeons might want to use such a system is that they can be very precise, which in turn can mean reduced trauma for the patient and a shorter recovery period. One common use for these robots is in hip and knee replacement procedures. The robot's job is to drill existing bone so that an implant fits snugly into the new joint. Because no two people have the exact same body structure, it's impossible to have a standard program for the robot to follow. That means surgeons must map the patient's body thoroughly so that the robot moves in the right way. They do this in a three-step process called **planning, registration and navigation.**

B. Telesurgical Systems

The DA VINCI Surgical System

A product of the company Intuitive Surgical[3], the DA Vinci Surgical System is perhaps the most famous robotic surgery apparatus in the world. It falls under the category of telesurgical devices, meaning a human directs the motions of the robot. In a way, this makes the robot a very expensive high-tech set of tools. On July 11, 2000, the U.S. Food and Drug Administration (FDA) approved the DA Vinci Surgical System for laparoscopic procedures, making it the first robotic system allowed in American operating rooms. The DA Vinci uses technology that allows the human surgeon to get closer to the surgical site than human vision will allow, and work at a smaller scale than conventional surgery permits.

ZEUS ROBOTIC SURGICAL SYSTEM

The ZEUS[2] Robotic Surgical System (ZRSS) was a medical robot designed to assist in surgery, originally produced by the American robotics company Computer Motion. Its predecessor, AESOP, was cleared by the Food and Drug Administration in 1994 to assist surgeons in minimally invasive surgery. The ZRSS itself was cleared by the FDA seven years later, in 2001. ZEUS had three robotic arms, which were remotely controlled by the surgeon. The first arm, AESOP (Automated Endoscopic System for Optimal Positioning), was a voice-activated endoscope, allowing the surgeon to see inside the patient's body. The other two robotic arms mimicked the surgeon's movements to make precise incisions and extractions. ZEUS was discontinued in 2003, following the merger of Computer Motion with its rival Intuitive Surgical; the merged company instead developed the DA Vinci Surgical System.

AESOP ROBOTIC SURGICAL SYSTEM

In the 1990s, Computer Motion[3] was a leading producer of medical robotics, manufacturing systems such as the HERMES Control Center and the SOCRATES Tele-collaboration Systems Computer Motion conducted its original research developing the AESOP (Automated Endoscopic System for Optimal Positioning) arm under a NASA SBIR (Small Business Innovation Research) contract. NASA funded the research in the hope that derivatives of such technology could help service the Space Shuttle in orbit, working on parts of the shuttle where humans cannot easily access or making other delicate repairs or adjustments.

AESOP was cleared for use by the FDA in 1994, and it became the first robot to assist in a surgery. AESOP's function is to maneuver an endoscope inside the patient's body during the surgery. The camera moves based on voice commands given by the surgeon. Voice activation of the AESOP arm allows the surgeon to position the camera while also controlling the other two arms of the ZEUS system. The endoscope can also be controlled by a computer which allows for more precise movements and also allows the endoscope to be inserted into the patient through a smaller incision (a key component of minimally invasive surgery)

C. Shared-Control Robotic Surgery System

Shared-control robotic systems aid surgeons during surgery, but the human does most of the work. Unlike the other robotic systems, the surgeons must operate the surgical instruments themselves. 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. Surgeons define safe regions as the main focus of a surgery. For example, in orthopedic surgery, the safe region might be a specific site on the patient's hip. Safe regions don't border soft tissues.

In orthopedic surgery, a close region is one that borders soft tissue. Since orthopedic surgical tools can do a lot of damage to soft tissue, the robot constrains the area the surgeon can operate within. It does this by providing responses, also known as force feedback.

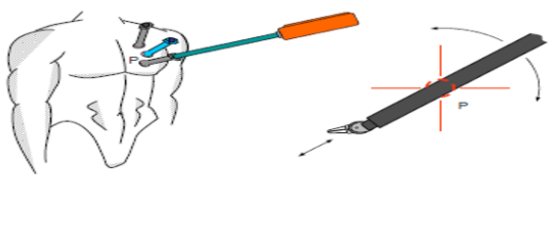

Fig 2: Location of endoscopic ports for instruments and camera

As the surgeon approaches the soft tissue, the robot pushes back against the surgeon's hand. As the surgeon gets closer to soft tissue, the instrument enters the boundary region. At this point, the robot will offer more resistance, indicating the surgeon should move away from that area. If the surgeon continues cutting toward the soft tissue, the robot locks into place.

Anything from that point on is the forbidden region.

Like the other robots we've looked at, shared-control system robots don't automatically know the difference between a safe region versus a forbidden region. The surgeons must first go through the planning, registration and navigation phases with a patient. Only after inputting that information into the robot's system can the robot offer guidance. Out of the three kinds of robot surgical system, the tele-surgical approach has received the most attention.

IV. ARCHITECTURE OF A ROBOTIC SYSTEM

Endoscopic surgery is a challenging technique for thoracic interventions. Its application is especially expedient in the field of heart surgery, because large intercostals cuts can be avoided. Therefore, the collateral surgical trauma of the patients is minimized, which results in quicker recovery of patients. In addition, the time of hospitalization and the infection rate can be reduced. Therefore, patients massively profit from this endoscopic treatment option.

On the other hand, surgeons have to cope with increasingly complex working conditions, but the design of intuitive user interfaces can help to overcome these barriers. Since endoscopic surgery is performed through a small port or “key-hole” in the patient’s chest surgeons must learn to operate with unfamiliar and often awkward surgical instruments. All movements are performed using “P” as fulcrum and visual impressions of the field of operation is provided by means of an endoscopic camera.Hence, the techniques of endoscopic surgery have been applied uncommonly particularly in the field of heart surgery. An important step to push this technology was the introduction of tele-manipulation, which was especially designed to overcome the fulcrum effect of endoscopic instruments. The surgeon no longer operates the instruments directly, but they are driven by a special device with a Cartesian user interface, which surgeons can handle as usual, i.e. like instruments for open surgery. Commercial examples for such systems are the DAVinci and ZEUS systems (the latter has been discontinued). They are good examples of how the proper design of user interfaces can push forward new technologies like minimally invasive and endoscopic surgery. They offer as much freedom of movement as the hand of the surgeon in conventional open surgery, thus providing six degrees of freedom instead of four, like conventional endoscopic instruments. In addition, they assist the surgeon with motion scaling, tremor filtering and a stereo vision interface at the input console.

Surgeons can now operate with a surgical mechatronic assistant in a comfortable, dexterous and intuitive manner. Despite the obvious potential advantages of robot assisted surgery, most researchers and surgeons in this area agree that the lack of a haptic interface is a crucial drawback of currently available systems. The inability of the operator to sense the applied forces causes increased tissue trauma and frequent suture material damage. The systems are tele-manipulator with no Cartesian position control (the control loop is implicitly closed by visual surveying of the surgeon). In addition, it is not possible for users from other fields to program new trajectories for those devices. Therefore, the main research interests are the construction and evaluation of force sensory / force feedback and the development of an easy-to-use interface for trajectory planning.

V. APPLICATIONS

Cardiac surgery Endoscopic coronary artery bypass (TECAB) surgery and mitral valve replacement have been performed. Totally closed chest, endoscopic mitral valve surgeries are being performed now with the robot.

Gastrointestinal surgery Multiple types of procedures have been performed with either the Zeus or DA Vinci robot systems, including bariatric surgery.

Gynecology Robotic surgery in gynecology is one of the fastest growing fields of robotic surgery. This includes the use of the DA-Vinci surgical system in benign gynecology and gynecologic oncology. Robotic surgery can be used to treat fibroids, abnormal periods, endometriosis, ovarian tumors, pelvic prolapse, and female cancers. Using the robotic system, gynecologists can perform hysterectomies, myomectomies[6], and lymph node biopsies. The need for large abdominal incisions is virtually eliminated. It can also be used for tubal re-anastomosis[7], hysterectomies and ovary resection.

Neurosurgery Several systems for stereotactic intervention are currently on the market. MD Robot's NeuroArm is the world’s first MRI-compatible surgical robot. Surgical robotics has been used in many types of surgical procedures including complement-image-guided surgery and radio surgery.

Orthopedics Surgical robotics has been used in many types of orthopedic surgical procedures including total hip arthoplasty: femur preparation, acetabular[8] cup replacement, knee surgery and spine surgery.

Pediatrics Surgical robotics used in procedures including: tracheoesophageal[10] fistula repair, cholecystectomy, nissen fundoplication[12], morgagni hernia repair, kasai portoenterostomy[11], congenital diaphragmatic hernia repair, and others. On January 17, 2002, surgeons at Children's Hospital of Michigan in Detroit performed the nation's first advanced computer-assisted robot-enhanced surgical procedure.

Radio surgery The Cyber Knife Robotic Radio surgery System uses image-guidance and computer controlled robotics to treat tumors throughout the body from virtually any direction. Urology

The DA Vinci robot is commonly used to remove the prostate gland for cancer, repair obstructed kidneys, repair bladder abnormalities and remove diseased kidneys.

VI. ADVANTAGES

A. Post-Surgery

1) Less Scarring
2) Faster Recovery Time
3) Tiny Incisions
4) 0% Transfusion Rate
5) Immediate urinary control
6) Less Post Operative pain

7) Significantly shorter hospital stay

8) Quicker return to normal activities

B. In-Surgery

Surgeons have enhanced view

Easier to attach nerve endings

Surgeons tire less

Fewer Doctors needed in the operation theatre

Smaller risk of infection

Less loss of blood

Cheaper for hospitals in the long run

Less anaesthesia required

VII. LIMITATIONS

A. Safety Concerns

In comparison to robots used in the industrial sector, medical robots present designers with much more complicated safety problems. Some of the most important factors which lead to such complexity are described below:
Human Presence
Fault Consequences
Non-Generic Task

B. Cost Consideration

The Robots that perform the surgeries cost around $750,000 to over $1 million. This is because they use extremely sensitive and experimental equipment that costs a lot of money. In addition to the cost of the machines the training that is needed for surgeons to learn how to use the systems is also very expensive. Because of the extreme cost of the machines at this point in time the procedures are slightly more expensive than a regular operation, but it does have its advantages. Many people in the medical field however believe that these surgeries will soon become more common and less expensive.

VIII. THE FUTURE

Robotic surgery is in its infancy. Many obstacles and disadvantages will be resolved in time and no doubt many other questions will arise. Many questions have yet to be asked; questions such as malpractice liability, credentialing, training requirements, and interstate licensing for tele-surgeons, to name just a few. Many of current advantages in robotic assisted surgery ensure its continued development and expansion.

For example, the sophistication of the controls and the multiple degrees of freedom afforded by the Zeus and DA Vinci systems allow increased mobility and no tremor without comprising the visual field to make micro anastomosis[7] possible. Many have made the observation that robotic systems are information systems and as such they have the ability to interface and integrate many of the technologies being developed for and currently used in the operating room. One exciting possibility is expanding the use of preoperative (computed tomography or magnetic resonance) and intra operative video image fusion to better guide the surgeon in dissection and identifying pathology. These data may also be used to rehearse complex procedures before they are undertaken. The nature of robotic systems also makes the possibility of long-distance intra operative consultation or guidance possible and it may provide new opportunities for teaching and assessment of new surgeons through mentoring and simulation.

Computer Motion, the makers of the Zeus robotic surgical system, is already marketing a device called SOCRATES that allows surgeons at remote sites to connect to an operating room and share video and audio, to use a “telestrator” to highlight anatomy, and to control the AESOP endoscopic camera. Technically, many remains to be done before robotic surgery’s full potential can be realized. Although these systems have greatly improved dexterity, they have yet to develop the full potential in instrumentation or to incorporate the full range of sensory input. More standard mechanical tools and more energy directed tools need to be developed.

Some authors also believe that robotic surgery can be extended into the realm of advanced diagnostic testing with the development and use of ultra sonography[9], near infrared and confocal microscopy equipment. Much like the robots in popular culture, the future of robotics in surgery is limited only by imagination. Many future “advancements” are already being researched. Some laboratories, including the authors’ laboratory, are currently working on systems to relay touch sensation from robotic instruments back to the surgeon. Other laboratories are working on improving current methods and developing new devices for suture-less anastomosis[7]. When most people think about robotics, they think about automation. The possibility of automating some tasks is both exciting and controversial.

Future systems might include the ability for a surgeon to program the surgery and merely supervise as the robot performs most of the tasks. The possibilities for improvement and advancement are only limited by imagination and cost.

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