Chapter 2

Robotic Surgery: Evolution, Current State and Future

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Abstract

The word robot was introduced into the modern language by the Kapek brothers. The Czech writer Karl Kapek in his play “Rossum’s Universal Robots” (RUR) protested against the rapid development of technology. He wrote about the fast evolution of robots with increased capabilities and further opportunity for them to rebel against the human race. Also his brother Joseph Kapek described automatization in a short story called “Opilec”

The world has always been fascinated by robots. Robotic technology has been used in various industrial and scientific fields for many years, but in Medicine it was introduced only in the late ’80s.

Robotic surgical systems are used nowadays in various surgical fields: Urology, Gynecology, Cardiology, Neurosurgery, and General Surgery etc. Today the most complex and efficient robot used in clinical practice is da Vinci surgical system developed by Intuitive Surgical Inc. in 1995. Robotic surgery has been shown to be safe, feasible and offers some considerable advantages over minimally invasive techniques: better visualization, improved dexterity by using Endowrist instruments with seven degrees of freedom, minimizes the fulcrum effect and filters out the physiological tremor of the surgeon. This systems can scale movements, improve hand-eye coordination and ergonomic position of the surgeon at the console. Main drawbacks of robotic systems may be extremely high costs and the lack of haptic feed-back, which we hope will be overcome in the future.
Robotic surgery has proven its value especially in procedures that are difficult to perform or inaccessible using laparoscopic techniques. It remains to be seen if robotic surgical systems will replace conventional laparoscopy in less difficult technical procedures.

Introduction

The first generation of surgical robots have already been installed in the operating rooms. These aren't true autonomous robots that can perform tasks on their own, they require a surgeon to operate and input instructions. We can say that today's medical robots have a great variety of clinical applications although these technology is only in its infancy.

History of Robotic Surgery

Robotic surgery was designed to overcome the limitations of minimally invasive surgery and to improve previously established procedural abilities of surgeons.

Minimally invasive surgery has become “the golden standard” in several pathologies due to its incontestable advantages compared to conventional surgical techniques: reduced postoperative pain, smaller incisions, reduced complications related to wound, less blood loss, reduces the length of hospital stay, etc. Despite all these, there are some shortcomings regarding the laparoscopic approach: bi-dimensional visualization, non-articulated instruments with 4 degrees of freedom, diminished sense of touch and, due to this, some complex surgical maneuvers become difficult [1].

Robotic surgery gives the surgeon the opportunity to perform complex procedures that may have been more difficult using traditional techniques. Broadly advantages of robotic surgery would be: better ergonomics for the surgeon who sits at a console remote from the patient, three dimensional visualization (the camera is controlled by the surgeon using a robotic arm), low complications due to increased accuracy. The new robotic instruments have 7 degrees of freedom and allow a larger range of motion and rotation similar to the human wrist.

The word robot is taken from the Czech word “roбота” meaning forced work. Surgical robotic platform used today started from a joint project of NASA and the US Department of Defense, which later found its surgical applications [2].

The first use of an industrial robot (PUMA 560) occurred in 1985 for a brain biopsy under CT guidance. It followed PROBOT in 1988, used in prostate surgery. ROBODOC was inaugurated in 1992 and it was the first robot approved by the FDA. It was used in orthopedics for hip prosthesis. In May 1998, Dr. Friedrich Wilhelm Mohr performed the first robotic assisted heart by-pass in the Cardiology Center from Leipzig, Germany.
Current State

AESOP

Automatic camera support system for laparoscopic/endoscopic camera (AESOP 3000) represented a milestone for robotic surgery and it was approved by the FDA in 1994 to assist surgeons in minimally invasive surgery. AESOP is a mechanical arm mounted to the operating table and used to position the laparoscopic camera. The camera is positioned by foot pedals, hand or voice control.

ZEUS Robotic Surgical System

Zeus robotic surgical system was manufactured by the American Company Computer Motion and was approved by the FDA in 2001. Zeus is composed of three robotic arms that are mounted on the operating table and a surgeon's console. One robotic arm is a voice activated robot and it is used to hold the laparoscopic camera (AESOP 3000). The other two arms are an extension of the arms of the surgeon. Zeus uses endoscopic instruments with seven degrees of freedom and articulated end effectors. The surgeon sits at the console and wears glasses that creates three dimensional image [2].

DA VINCI robotic system

Da Vinci robotic system was developed by the American Company Intuitive Surgical, Inc., Sunnyvale, CA and obtained the FDA approval in September 2001. Later, in 2003 the two companies Computer Motion and Intuitive Surgical merged, resulting a single robotic platform on market, Da Vinci. Zeus platform is no longer in use.

Da Vinci surgical robotic system has three main components: the surgeons console, the surgical cart and the Vision System. The surgeons console is located in the operating room, but at a certain distance from the patient (recently a distance of 10 m from the operating table is accepted). The computer system that coordinates the entire system is located in the surgeon's console. The surgeon sits at the console with the head placed in a viewing space that provides a three dimensional image of the operating field and keeps his hands in control grips in line with the visual axis. Surgeons hand motions are transmitted to the robotic arms which manipulate the instruments.

From the console, surgeon may change instruments between them and can control the laparoscopic camera. Surgeon's positions at the console is very comfortable and removes one of the disadvantages of laparoscopic surgery.

The video system consists of two sources of light, two video processors and a synchronizer.

The surgical cart has three or four robotic arms where the instruments can be attached by an eight millimeters specific adapter [3].
The robotic arms move around the pivot points. One arm holds the laparoscopic camera and the others hold Endowrist instruments that are designed with seven degrees of freedom. That means a range of motion similar or greater than the human wrist. This type of instruments presents some advantages over conventional laparoscopic instruments such as: reduction of physiological human tremor, finger-tip control, motion scaling. The interface of Da Vinci system recognizes the function of the instrument and detects when an instrument needs to be replaced. There is a great variety of Endowrist instruments that allow a quite large variety of surgical procedures such as monopolar and bipolar cautery instruments, Da Vinci Harmonic, Da Vinci PK Dissection Forceps, laser, needle drivers, and grasping instruments designed for different types of tissues, retractors. Other specialized instruments are: clip appliers, cardiac stabilizers, probe graspers [4].

Advantages of Robotic Surgery

The three dimensional view of da Vinci system allows a high definition image and increases accuracy by providing ten to fifteen times magnification.

The system can also scale movements. The large motions are converted in small movements inside the patient. Fine movements are facilitated due to the software that filters out the physiological tremor of the surgeon. This fact makes micro-anastomosis possible.

Surgeon’s position at the console is very comfortable compared to conventional laparoscopic surgery.

Compared to conventional laparoscopic surgery where the surgeon’s movements are counterintuitive, in robotic surgery the movements are intuitive (a movement to the left produces a movement to the left on the video screen). Hand-eye coordination is improved because the visual axis is aligned with the surgeon’s hand.

It eliminates the need for an assistant to hold the laparoscopic camera by the fact that the surgeon controls the camera hold in position by the robotic arm and also eliminates the resistance given by the abdominal wall.

EndoWrist instruments are provided with seven degrees of freedom, while the instruments used in laparoscopy are straight and have diminished degrees of freedom. This is a considerable advantage because they mimic the movements of the human wrist [5].

Finally, the learning curve is shorter than in laparoscopic surgery [6].

Disadvantages of Robotic Surgery

The main disadvantage of using robotic surgery is the high costs of purchasing the robot, the instruments and then the maintenance of the system. It is mandatory, the existence in the operating room of a complete team trained to install and use the da Vinci system in conditions of maximum safety for the patient. Training this team further increases costs.

The set-up time for the robotic system is longer at the beginning of each robot-assisted operation, even with the
presence of a well-trained team. Definitely this issue will be overcome with the further development of this type of technology.

A disadvantage worth mentioning is the lack of sense of touch which increases the risk of tissue damage.

The large size of the device and its arms favors collisions during surgery and makes difficult to position an assistant at the operating table. Also there is a risk of technical problems that can occur when electronic or mechanical devices are used [7].

The advantages and disadvantages of robotic versus laparoscopic surgery are summarized in Table below:

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Robot assisted surgery</th>
<th>Conventional laparoscopic surgery</th>
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<tbody>
<tr>
<td></td>
<td>• 3D view/high definition image</td>
<td>• Well established technology</td>
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<td></td>
<td>• Improved dexterity</td>
<td>• Easily accessible and affordable</td>
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<td></td>
<td>• Ability to scale motions</td>
<td>• A certain degree of tactile feedback</td>
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<td>• Tremor filtration</td>
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<td></td>
<td>• Intuitive movements</td>
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<td></td>
<td>• Better hand-eye coordination</td>
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<td></td>
<td>• Seven degrees of freedom</td>
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<td></td>
<td>• Micro-anastomosis possible</td>
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<td></td>
<td>• Ergonomic position of the surgeon</td>
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<tr>
<td>Disadvantages</td>
<td>• Very expensive</td>
<td>• 2D visualization</td>
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<td></td>
<td>• Enlarged team to operate</td>
<td>• Limited degrees of freedom</td>
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<td></td>
<td>• Longer set-up time</td>
<td>• Counterintuitive movements</td>
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<td></td>
<td>• Absence of the sense of touch</td>
<td>• Low dexterity</td>
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<td>• Enhanced physiological tremor</td>
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Some Application of Robotics in General Surgery

Robotic surgical systems are used nowadays in several disciplines such as: Urology, Cardiology, Gynecology, General Surgery, Neurosurgery etc.

General surgery has been using robotic surgical systems less than other surgical branches. Da Vinci surgical system has been used in a variety of interventions in General Surgery such as: cholecystectomy, antireflux surgery, Heller myotomy, bariatric surgery, colorectal surgery, esophageal surgery etc.

Cholecystectomy

Cholecystectomy was the first surgical robotic assisted procedure and it was performed in 1997 by Leman, Himpens and Cadiere. Although a considerable number of cholecystectomies were performed using da Vinci surgical system, studies prove that there is no advantage over laparoscopic cholecystectomy. Operating time is usually longer and there is no clinical postoperative benefit. Nevertheless, cholecystectomy remains one of the main procedures for learning the basic skills in robotic surgery.

Anti-Reflux Surgery

In 1999 Cadiere reported the first two cases of robotic assisted fundoplication. A number of clinical trials compared robotic assisted Nissen fundoplication to conventional laparoscopic technique. Operative time was sig-
nificantly shorter for laparoscopic surgery. This was due to increased time to set-up the robot, trocars positioning was more difficult and it took more time to suture the wrap. Costs were also much higher for robotic surgery. But no differences were found between the two techniques in term of clinical, endoscopic or functional outcomes [6].

**Heller Myotomy**

Laparoscopic Heller myotomy has become the golden standard in treatment of achalasia in the past few years. In approximately 5% of the cases, mucosal perforation happens during myotomy. The main advantage of robotic assisted surgery over conventional laparoscopy would be that reduces the rate of mucosal perforation. This occurs probably because of the more complex and precise movements, tremor filtration and 3-D image that robotic system offers. Even if perforation occurs robotic systems makes it easier to repair. A prospective, non-randomized study of 121 patients, which compared robotic to laparoscopic Heller myotomy, proved that the operating time was longer for the robotic assisted surgery, but there were no mucosal perforations in the robotic group versus 16% in the laparoscopic group. Due to the studies published in the literature robotic Heller myotomy is safe and also efficient.

**Bariatric Surgery**

Robots are used in a wide range of bariatric surgical procedures such as: gastrojejunostomy, Roux en Y gastric by-pass, gastric banding, and biliopancreatic diversion.

Robotic systems are particularly useful in super obese patients because of the wristed instruments with increased degrees of freedom and the strength of the robotic arm.

**Colorectal Surgery**

In colorectal surgery, robotic systems are still in development. The colorectal surgeons first used da Vinci system in 2002. Difficulties have arisen especially when dissection was necessary both up to splenic flexure and in the pelvis. Otherwise clinical outcomes are similar to conventional laparoscopy, but costs are much higher. Operating time is longer in robotic colorectal surgery because of additional set-up time. A meta-analysis comparing low anterior laparoscopic resection for rectal cancer to robotic assisted surgery shows that robotic low anterior resection has some benefits such as: lower complications rate, shorter hospitalization, fewer circumferential margin involvement, and conversion was required in fewer cases. No differences were detected regarding the number of lymph nodes that have been removed and the bowel function [5].

**Future Developments**

Robotic systems have made a significant contribution to all surgical branches in the past few years. Scientists are trying to overcome the electromechanical limitations of actual robotic systems. In the future robotic systems with smaller instruments, lower overall costs, shorter set-up time with the help of a very well trained team and remote telementoring will become available.
One disadvantage of telerobotic devices is the lack of haptic feedback. Currently research is in progress to overcome this shortcoming.

A safety issue for telesurgery is related to signal latency. Latency represents the time between when the controllers are maneuvered and when the robotic arms itself moves. Some authors argue that a latency greater than 200 msec requests distracting compensation from the surgeon. This problem will be overcome in the future when faster signal transfer capacity will be developed. Ethical issues still remain a subject of discussion regarding telesurgery.

Miniature robots that can be placed into body cavities and perform certain tasks are very promising. Small robots have been deployed transgastrically into the peritoneal cavity to visualize and manipulate tissues at the University of Nebraska. This miniature robots are still developing and are very promising.

One thing is certain: robotic surgery will keep evolving and in the future will become more common and will have more and more followers [6].

Conclusion

We have every reason to believe that the future of robotics in medicine will be full of surprises. These technology will be developed further more in the years to come and it is very likely to replace minimally invasive surgery in a great variety of procedures.

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