Robotic Surgery
The ultimate surgeon
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Robotic Surgery

Robots are slowly taking over the world of surgery. Why? There are numerous reasons. For one, the machines have higher precision and more stable “hands and fingers”. They will not tie large knots with thick sutures and will not cut into healthy, normal tissues. Secondly, infections are less likely. Since these robotic surgeons do not need to insert large incisions in the body, depending on the robot, only a couple miniature holes need to be cut, thus, allowing minimal infection. The insides are not exposed to any bacteria and recovery time is now shortened. As well, with great cuts and openings there is more pain afterwards, so pain would be reduced too if the incisions were smaller.

Along with the many positive aspects of robotic surgery, there are also many possible risks and negative outcomes. Such risks can be simple like, power outages, computer crashes, various other electric problems, elevated costs and the size. Hospitals now have backup generators and amazing computer systems so most of these problems are gone, yet the cost still remains an issue.

Human and Robot strengths and weaknesses

All humans, animals and machines in our world have their own strength and weaknesses, positives and negatives, advantages and limitations. For robotic and human surgeons, there are many.

Robot strengths and limitations

Robots are amazing; they function like no human with only electricity and software. However, robots in surgery operate on a whole other level. These machines can run non-stop for however long it takes to complete the surgery whether it is succeeds or fails (Health and Wellbeing 2007). Harvard 2005 and Heart Surgery 2006 state that robotic surgeons, such as the Da Vinci system™, are stable, untiring, quiet machines that will perform heart surgery in 50 minutes and not even blink with disgust. These robots are not “squeamish”. They cannot be infected with AIDS or other diseases and are resistant to radiation (Harvard 2005). In addition, these robots have great geometric accuracy and can use diverse sensors (chemical, force, acoustic, etc.) in surgery (Harvard 2005, BMJ 2007). These “surgeons” can also be designed for a large range of scales and are sterilized rather easily.

Alongside their strengths are their weaknesses, both internal and external their shortcomings consist mostly in areas of simple human characteristics (Harvard 2005). While amazing surgeons, robots would go nowhere if they had to think and analyze for themselves, at least not with current technology. Health and Wellbeing 2007 states that robotic surgeons have terrible judgment, limited dexterity and hand-eye coordination. These simple human
characteristics come that natural to us. Robots are not people though, so they are weak in these areas and humans must improve them in the future for the sake of robotic surgery and saving people’s lives. In addition to these limitations, their technology, if very sophisticated, is limited to only one type of surgery for a given robotic surgeon. This means that a hospital would have to invest in many robots to cover all their surgery. Also, technology is in a state of flux. In other words, it is evolving and can be unstable at times. These robots can perform heart surgery, but cannot complete relatively simple procedures like mending bones (Harvard 2005).

Robotic surgeons are amazing advantages to have in the medical field. However, they are still in their infancy and are far from ready to replace humans.

Human strengths and limitations

The strengths of human surgeons are basically the weaknesses of robot surgeons and vice versa. Humans have strong hand-eye coordination and are extremely dexterous at a human scale (Harvard 2005). Humans are flexible (varies from surgeon to surgeon), adaptive and most have great judgment. Health and Wellbeing 2007 declares that these surgeons can integrate extensive and diverse information and, can use qualitative information rather easily. Finally, human surgeons are easy to instruct and debrief, that is, if they are patient (da Vinci System 2004).

As for the weaknesses of human surgeons, they are such as to make a grave difference. For example, humans are prone to fatigue and tremor, which can cause major problems if a surgeon’s hand jerks suddenly (Harvard 2005). As well, our hands are not developed enough to make such fine and subtle movements inside a patient’s body and they have limited dexterity outside of the natural scale (Health and Wellbeing 2007). As stated by Heart Surgery 2006, humans do not have the fine geometric systems internally that robots do. Consequently, they have limited geometric accuracy. Finally, human surgeons are extremely susceptible to infection and radiation (Harvard 2005, Health and Wellbeing 2007).

Benefits to the patient

The revolution of robotic surgery has brought many benefits to patients undergoing surgery. These are classified into two main areas, namely “minimally invasive” and “Health” (da Vinci 2007).

In the area of “Minimally invasive”:

1) Improved cosmesis outcome (reduced intervention areas, less scaring, etc)
2) Fewer complications (da Vinci system 2004) such as less blood loss, less pain, etc.

In the area of “Health”:
1) Shorter hospital stays
2) less patient morbidity
3) shorter convalescence for patients (after the hospital)
   a. fewer lost days from work (da Vinci system 2004)
   b. faster return to normal daily activities (jogging, biking, etc)

Studies indicate that in many cases patients have better clinical outcomes when compared to human surgery (da Vinci 2007).

Problems

Advances in robotic surgery are not without problems such as size of the machines, technical issues and, of course, very costs.

Size

According to BMJ 2007 and da Vinci System 2004, the surgeon console, including the robotic arm cart and the video cart take up considerable space, approximately 25 square feet, whereas a human surgeon would occupy about 15 square feet. This is a huge difference because space is at a premium in hospitals. It also takes a substantial amount of time to prepare robotic surgeons for surgery. In addition, a bedside nurse is required (which adds to the space requirements).

Technical issues

In the area of technical issues, two problems draw a considerable amount of attention at the moment. The primary concern is the lack of tactile feedback available with the current system (da Vinci system 2004). However, new systems are being developed to address this. According to Robot-Assisted Surgery 2005, other issues include the possibility of system breakdown and some lack of flexibility with the surgical robotic arms. As said before though, these problems are always being worked on and will soon be overcome.

Cost

Cost is a major issue when it comes to robotic surgery. According to many studies (Harvard 2005, da Vinci 2004, Health and Wellbeing 2006), it is estimated that the initial cost for prototypes like the da Vinci system™ is around $3 million U.S. However, other systems can be much more expensive. Perhaps if this was the whole cost, it would not be so grim. However, all over the world, these machines are being produced, so it is a constant three or so million dollars that is being spent (Harvard 2005). Along with the initial payment of around $3 million, there is tax for one, the fee of shipping, installation and warranty (if desired). These other costs bring the total cost to more than fees are anticipated to range from $1.1 to 1.4 million (da Vinci system 2004). Therefore, after ordering, shipping and installing the equipment, along
with paying warranty and tax, one who wishes to purchase, a robotic surgeon, must have around 4.5 million dollars, which is a hefty sum of money for most hospitals.

The payment is still not over however. In addition to the initial cost of these machines, there are the costs of maintenance and replacement of the equipment. Health and Wellbeing 2006 states that, the average cost per surgery is now $4000 because parts must be replaced and/or repaired. After around 10 operations, many pieces of equipment must be replaced by new ones because they cannot function properly anymore (Harvard 2005). The estimated annual cost of maintenance and operating costs are $365 000 combined, and do not forget the tax (comes to around $365 000). Therefore, in the first year, on an average rate, it would cost approximately $5.2 million to purchase and operate a robotic surgeon.

To the cost of equipment, we must add the fee to train surgeons and nurses. To do so, hospitals must invest in simulators and actual bodies so that they can practice on. According to BMJ 2007, the cost to train a surgeon and his staff is $190 000.

During the first year alone, the total cost is approximately $5.5 million and $600,000 for every year thereafter. On top of all this, each robot can only perform the one surgery for which it was designed. For example, a surgeon designed for knee surgery will not be able to operate on a hip surgery. Therefore, hospitals must buy multiple robotic surgeons for multiple surgeries, which results in millions and millions more (Harvard 2005).

There is one last issue with the cost; the hospitals themselves must pay for these costs, not the government (Health and Wellbeing 2007). Therefore, hospitals must charge patients a higher fee for robotic surgery, limiting the opportunity for many to have robotic surgery as it is quite expensive and patients resist paying more. Even though it is extremely expensive for hospitals to purchase and maintain robotic surgeons, studies seem to indicate that as time advances and technology improves, cost will decrease (Harvard 2005) and adoption will increase.

Types/protocols

Similarly to human surgeons, whom vary in nationality, character and personality, robotic surgeons come in different types as well. Namely (According to BMJ 2007), active, semi-active and passive.

Active
“Active” is defined (Dictionary.com) as “to be in a state of existence, progress, or motion.” Therefore, an active robot is one that actually moves (BMJ 2007). This category includes laparoscopic camera holders, telemanipulators, and robots used for burring out tissue. Stated by Harvard 2005, a few examples of active robots are the AESOP robotic system, the Da Vinci system and the Zeus system.

Passive

Opposite to active robots, a passive robot is not in motion. Dictionary.com, defines passive as “to not participate readily or actively; inactive.” This category consists mainly of a robot to position a fixture appropriately and is then turned off. After the machine is off, the surgeon would insert his/her instruments and continue with the surgery (BMJ 2007). For example, a passive robot would be used to help position a device for guiding neurosurgical biopsy needles.

Semi-active

Semi-active robots fall somewhere between active and passive robot. This category consists of robots that require input from the surgeon to carry out power directed activity. The Acrobot robot is an example of such. This robot is a Prosthetic knee implantation system. (BMJ 2007)

Table 1: Listing of numerous robots, their type, and their use.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Use</th>
</tr>
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<tbody>
<tr>
<td>Zeus</td>
<td>Master-slave</td>
<td>General, cardiothoracic, and gynaecological surgery (BMJ 2007)</td>
</tr>
<tr>
<td></td>
<td>telemanipulator</td>
<td></td>
</tr>
<tr>
<td>Endoassist</td>
<td>Active camera</td>
<td>MAS camera manipulation (synchronised to surgeon’s head movements) (BMJ 2007)</td>
</tr>
<tr>
<td>Fips</td>
<td>Active camera</td>
<td>Minimal access surgery camera manipulation (finger ring joystick controlled) (BMJ 2007)</td>
</tr>
<tr>
<td>endoarm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AESOP</td>
<td>Active camera</td>
<td>Minimal access surgery camera manipulation (voice controlled) (BMJ 2007)</td>
</tr>
<tr>
<td>Minerva</td>
<td>Active surgical</td>
<td>Stereotactic neurosurgery (BMJ 2007)</td>
</tr>
<tr>
<td>Acrobot</td>
<td>Semi-active surgical</td>
<td>Prosthetic knee implantation (BMJ 2007)</td>
</tr>
<tr>
<td></td>
<td>(synergistic)</td>
<td></td>
</tr>
<tr>
<td>CASPAR</td>
<td>Active surgical</td>
<td>Prosthetic knee implantation (BMJ 2007)</td>
</tr>
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Safety features

The field of robotic surgery requires many safety features to protect patients ranging from backup generators to mathematical logic. These safety features can be classified mainly into two distinct categories, hardware-related and software-based (Harvard 2005).

Hardware

Hardware-related security features range from simple to very complex and difficult ones. “Simple” safety features are uncomplicated things such as when the surgeon removes his head from the console (perhaps take a sip of his or her coffee) the camera will cease to move, the instruments will always freeze and the whole system will enter a standby mode (BMJ 2007). An example of a “complex” safety feature is the AESOP endoscope pointing robot (Harvard 2005). The AESOP robot is used for minimally invasive general surgery. The end of the arm of the AESOP is attached to the endoscope through a gimbal and magnetic coupling. Since the incision in the patient’s body prevents lateral movement of the endoscope tube, the gimbal allows the endoscope tube to pivot about the incision while the robot moves the endoscope tube, in any direction, above the patient (HF issues 2008). This feature makes it, impossible for the endoscope tube to perform lateral movement thus reducing pain to the patient’s body. Harvard 2005 states that another safety feature of the AESOP is the magnetic coupling. This acts as an emergency release. If ever the forces on the endoscope tube exceed the magnetic holding force, the endoscope will disconnect from the arm and will usually fall harmlessly on the patient’s abdomen. Other robotic surgery systems use low-pressure pneumatic power to reduce the dangers of electrical actuation (BMJ 2007). As well, this feature limits the size of the robots workspace in the patient’s body to eliminate the possibility of damage to tissue away from the intended surgical site (Harvard 2005).

Software

There are many software safety features in robotic surgery systems. Most systems use mathematical logic, or algorithms, to control safety features. Ng & Tan, along with other companies, use mathematical logic to analyze the robot’s program flow and determines if it is
possible for the control to evade safety features incorporated into the code. It is a completely independent safety monitor that can arrest the servo runway, if it detects anything is abnormal. *BMJ 2007* states that such safety features can detect “out-of-safe-boundary” conditions. It is possible to do so by using joint encoder signals (Harvard 2005).

**Knee surgery**

Another software safety feature that is installed in certain systems is a nifty feature in knee surgery systems. It allows the surgeon to control the cutting tools and camera while the robot prevents any motion to occur outside of the designated surgery area (Harvard 2005). This aids the surgeon tremendously because he does not have to worry about movements of the body while he is about to make a very important knot or incision (BMJ 2007).

**ROBODOC hip replacement**

One final example of safety features in robotic surgery is one that lies in the ROBODOC hip surgery system (Harvard 2005). This feature is basically the opposite of the knee surgery feature. In this safety attribute, the **robot** moves the cutting tools and camera, while the **surgeon** is the one who keeps everything under control and monitors the progress.

**Areas of use**

Although robots are not be able to perform all types of surgeries yet, they can perform quite a few, and they do so with extreme efficiency. Robotic surgery systems are used in the fields of orthopedics (joints), neurology (brain), urology (gall bladder and prostate) and cardiology (heart).

The following are the areas of surgery, along with numerous references describing the surgery process.

**Orthopedics (joints)**


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**Neurology (brain)**

Evolution of robotic surgery

Copied from Robot-assisted surgery 2005, in the following lie important dates in robotic surgery.

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

1992 - Integrated Surgical Systems introduced RoboDoc for orthopedic surgery, specifically total hip arthroplasty. This robotic system allowed orthopedic surgeons to pre-plan their operations while performing more accurate surgery. This robot gained acceptance for use in Europe but still has not received FDA clearance for marketing in the U.S

November 7, 1992 - The first robot-assisted human hip replacements using Robodoc, on a 64-year-old man suffering from osteoarthritis. Ten more robot-assisted human hip replacements using Robodoc were performed at Sutter General Hospital, Sacramento, Calif., under an investigational device exemption (IDE) approved by FDA Oct. 9,1992

December 1993 - the FDA approved the AesopTM 1000, a robotic system used for holding an endoscopic camera in minimal invasive laparoscopic surgery, developed by computer motion
1995 - Frederic Moll, M.D., Robert Younge and John Freund, M.D. formed Intuitive based on foundational robotic surgery technology developed at SRI International (formerly known as Stanford Research Institute)

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

1997 - Jacques Himpens and Guy Cardier in Brussels, Belgium used the da Vinci by Intuitive Surgical Inc. system to perform the first telesurgery gall bladder operation

1997 - Integrated Surgical Systems Inc. purchased Innovative Medical Machines Int. (MMI), its Neuromate System and extended its field of robotic from orthopedics to neurosurgery

May 1998 - Carpentier et al. performed the first mitral valve repair using an early prototype of the da Vinci articulated intracardiac "wrist" robotic device

1998 - Dr. Frank Diamiano performed the first procedure in the United States with a reanastomosis of a fallopian tube using the Zeus system

September 24, 1999 - Dr. Boyd of London Health Sciences Centre's (LHSC) university performed 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

November 22, 1999 - The first closed-chest beating heart cardiac hybrid revascularization procedure is performed at the London Health Sciences Centre (London, Ontario). Dr. Douglas Boyd used Zeus to perform an endoscopic, single-vessel heart bypass surgery on a 55 year-old male patient's left anterior descending artery

December 9, 1999 - Dr. Ralph Damiano, Jr., at the Milton S. Hershey Medical Center at Penn State College of Medicine in Hershey performed the first robotic assisted beating heart bypass in the United States using the Zeus Robotic Surgical System

July 11, 2000 - Intuitive Surgical Inc. received clearance from the FDA to market the da Vinci® Surgical System in the United States for use in laparoscopic surgical procedures

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

October 9, 2001 - ZEUS® Robotic Surgical System from Computer Motion receives FDA regulatory clearance with the FDA decision for U.S. surgeons to use a variety of instruments to perform a wide range of robotically assisted laparoscopic and thoracic procedures
August 2001 - The CyberKnife® became the first image-guided robotic technology to receive FDA clearance for non-invasive cancer surgery to provide radio-surgery for lesions anywhere in the body when radiation treatment is indicated

September 7, 2001 - ZEUS robotic system developed by Computer Motion was used in the trans-Atlantic operation. A doctor in New York removed the diseased gallbladder of a 68-year-old patient in Strasbourg, France

October 1, 2001 - FDA cleared the marketing of the CyberKnife with Dynamic Tracking Software (DTS) developed by Accuray Incorporated to provide radio surgery for lesions, tumors, and conditions anywhere in the body when radiation treatment is indicated

March 7, 2000 - Two leading medical robotic companies Intuitive Surgical Inc. and Computer Motion Inc. announced the merge agreement, combining the two companies’ products for operative surgical robots, telesurgery and operating room integration

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

Apr 9, 2005 - Surgeons at the University of Illinois Medical Center at Chicago successfully performed a laparoscopic right hepatectomy, removing approximately 60 percent of her liver, and the tumor using the da Vinci® Surgical System
References


