The Robots Are Coming: 
The History – and Future Prospects – of Telerobotic Surgery

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Telerobotic surgery has come a long way in its brief history. While teleconsultation continues to be used today, the advent of high speed communications and increased computational power is making long distance remote control of operating instruments, termed telepresence surgery, a reality. Based on laparoscopic technology, telerobotic surgery was tested first on animals and, more recently, on humans with success. The technology offers several advantages, including improved accuracy and the ability to bring difficult procedures to rural and remote locations where trained surgeons are not available. While various technical difficulties and ethical issues must still be worked out, the advantages of remote surgery ensure that this technology will continue to be developed for widespread implementation in the years to come.

Surgery, which is arguably as much art as science, has evolved from the early crude days of trepanation and battlefield amputations to modern procedures such as complex neurosurgeries and minimally invasive laparoscopic interventions. Just as the artist can do little without his brushes, however, the surgeon is virtually useless without his tools, and it is perhaps the development of these tools, which has directly driven the evolution of surgery. While various tools such as scalpels, loops, stitches, anesthesia and antiseptics have each expanded the range of possibilities for procedures, some of the newest tools to enter the surgical arena are computers and robotic instrumentation.

Teleconsultation and the dawn of remote surgery

While the advantages of computer and robotic assistance in surgery, in terms of enhanced accuracy and control may seem obvious, one of the most interesting and useful applications of this technology is to perform surgeries remotely. Patients in rural and remote locations often do not have access to advanced surgical care due to a lack of qualified personnel. This is not only the case in both wartime battlefields and third world countries, but is, unfortunately, a problem in many remote areas of Canada as well. Surgical care in these locations is either impossible or requires transportation to an urban center over long distances.

The first attempts at remote care were really what would be termed teleconsultation. The 1960’s saw the beginning of electronic transmission of radiological films, while the 1970’s brought the ability for practitioners to consult with experts remotely over video-conference systems. In a surgical implementation of teleconsultation, a remote videoconferencing system was set up in the operating room and was linked to an expert physician at an urban center. This ‘remote’ surgeon did not actively participate in the procedure, but rather offered advice or guidance to the attending surgeon at critical points. At best, electronic remote control of the video camera was available, but little else. While definite benefits in terms of transmitting expertise and training inexperienced surgeons could be realized with this setup, true remote surgical control was impossible.

Laparoscopic surgery: a catalyst for advancement of telerobotic surgery

This changed with the advent of a robotic system aimed at assisting in laparoscopic procedures. Laparoscopic surgery utilizes a miniature camera (i.e., laparoscope) and small surgical tools which are inserted into the body via tiny incisions and controlled via external manipulators. Minimally
invasive surgery performed using laparoscopy provided several advantages to the patient: less pain, a shorter hospital stay, better cosmetic outcome and faster recovery. Unfortunately, this surgical technique, in its original conception, had several shortcomings. The laparoscope produced only a 2-dimensional view of the surgical area, and hand-eye coordination was difficult due to the need to look at a monitor instead of one’s hands. Furthermore, the laparoscope was held by an assistant, and therefore direct was taken out of the hands of the surgeon. Perhaps most importantly however, laparoscopy, by its very nature, introduced amplification of tremor, loss of degrees of freedom in manipulation, and the brought the requirement for making non-intuitive motions when performing a procedure.

In an attempt to overcome the inherent limitations of laparoscopic surgery, research supported by the United States Defense Department’s Star Wars program was undertaken in the early 1990s at the Stanford Research Institute to develop a ‘master-slave telemanipulator’ – a system wherein a computer and robotic instrumentation intervened between the surgeon and the patient. Ironically, the original goal of this technology was to enable actual manipulation of surgical instruments by remote surgeons, a concept termed telepresence surgery. It was hoped that this technology would be useful in performing remote trauma surgeries on the battlefield or outer space, where surgeons could not venture. Unfortunately, while a system was developed, it lacked the required degrees of freedom necessary for efficient surgery, and its large size precluded widespread use. When this research program ended in 1994, the patents were sold to a private company, which continued development to produce what is now called the ëda Vinciî robot system. This robotic system builds on traditional laparoscopic technology, rectifying some of its flaws while introducing the capacity for remote manipulation. The first refinement is that the camera platform is stable, and can be controlled by the surgeon’s feet or voice commands, eliminating the need for an assistant. Second, visualization is greatly enhanced with a 3-dimensional magnified system to simulate natural vision, or alternately 2-dimensional displays positioned near the hand controls. Moreover, since physical manipulation of the controls is processed by a computer, tremors can be digitally filtered out preventing undue error. Finally, the use of motion scaling, which reduces large movements to fine ones, allows surgeons to perform actions which were previously impossible due to their delicacy.

Telerobotic surgery matures
Early telepresence surgery research was extremely limited, and being hampered by technical limitations, was carried out only on animal models. Advanced manipulation techniques were not possible due to lack of adequate computational power and communication bandwidth. An early ‘procedure’ was performed in 1993 by issuing keyboard and mouse commands to manipulate an echographic probe, biopsy needle and scalpel over a transatlantic fiber optic telephone link to remove a cyst from a pig’s liver. Unfortunately, transfer of real-time video over the wired network was technologically impossible at the time due to bandwidth constraints; consequently, relatively expensive satellite links were required.

One of the leading difficulties in developing clinically viable telerobotic surgery has been the requirement of minimal time lag between the issuing of commands, actual surgical action, and reception of visual confirmation on the screen. This lag is influenced by multiple factors including time required for converting video and movements into the appropriate signals and the inherent delay in the communication network itself. Experiments have determined that the acceptable limit for safe surgery is 330 milliseconds. Even with the satellite video link in early experiments, overall delays of approximately 2 seconds were inherent in the technology – obviously far from acceptable for a real-time surgical procedure. Accordingly, it was estimated that feasible distances for remote surgery could not exceed several hundred kilometers. This was, however, disproved in subsequent years.
The first successful telerobotic procedure on a human was performed in 1995 by Dr. Alberto Rovetta in Italy -- a prostate biopsy was obtained from a patient 5km away via a robotic telemanipulator. While this experiment was promising, the original dream of a true long-distance fully controlled remote surgery was not realized until several years later when suitable high speed, high bandwidth communications and adequate computational power were available. On September 7th 2001, the world’s first trans-Atlantic complete operation, termed the “Lindberg operation”, took place. In this case, a patient in Strasbourg underwent a cholecystectomy with the controlling surgeons located in New York. This surgery was completed using a second commercially available robotic surgery system, called ZeusT, which featured a robotic endoscope positioning system called AESOP (Automated Endoscope System for Optimal Positioning). With a time delay of 155 milliseconds, the surgery was deemed safe, and no post-operative complications were noted. While telerobotic surgery is still far from mainstream, several surgeries have already been successfully completed including fundoplications, sigmoid resections, hemicolectomies, inguinal hernia repairs, colectomies, radical prostatectomies and nephrectomies. Other surgeries, including the first Canadian remote coronary bypass (1999) and mitral valve replacements were performed at London Health Sciences Center.

The challenges ahead
While remote surgery seems promising, several issues remain to be worked out. For one, current systems lack tactile feedback, although this is actively being developed. Without the ability to feel resistance in tissues, the surgeon must carefully review visual information to avoid making an accidental tear. Another problem...
stems from the compliance of certain tissues; for instance, the robotic manipulators have difficulty in grasping slippery surfaces. However, these obstacles will likely be surmounted in future versions of the technology, and a testament to the incredible functionality already achieved by these robots can be made by observing the actions of the surgeons. Almost without fail, surgeons using the telepresence system unwittingly find themselves removing their hands from the manipulators to retract a piece of tissue, the advanced technology making them forget for a moment that they are not really at the surgical site.

While telepresence surgery holds much potential for fulfilling many of today’s remote surgery requirements, it also brings with it a variety of unique challenges. First, the cost of equipment and communication links is high. Training surgeons with the technology is time-consuming, as is setting up the equipment. Second, it is essential that an adequately trained surgical team be present at the surgical site, ready for emergency intervention in case the equipment malfunctions, or the communications line is severed. This ties down surgeons who might otherwise be performing their own operation elsewhere. Similarly, significant time is required to switch surgical instruments on the machine between operations. Finally, there are many legal and ethical questions that must be answered before remote surgery can be widely adopted. Medical licensing over provincial and international borders is unclear, at best. Perhaps more importantly, however, the traditional patient-clinician relationship will have to be redefined, as the patient may never meet his surgeon face to face.

The prospects for telesurgery are exciting. From remote surgeries in space to mobile hospitals in war zones or developing countries, the possibilities are endless. While we have
already come a long way from the early surgeries performed with nothing more than a blade, the continuous evolution of computers, communications systems and mechanical surgical equipment ensures that many exciting developments in the field of telesurgery will take place in the years to come.

References