

The cutting edge in surgery

Telesurgery has been shown to be feasible—now it has to be made economically viable

In September 2001, a hospital in Strasbourg, France, probably broke the record for the most expensive standard surgery in history by removing the gall bladder from a 68-year-old woman for the princely sum of more than €1 million. But it was not the exorbitant cost of the operation that made the headlines in the popular and biomedical press. It was the fact that it was the first example of transatlantic telesurgery, with the patient in Strasbourg and both surgeons, Jacques Marescaux of the European Institute of Telesurgery at the University of Strasbourg and Michel Gagner of New York City's Mount Sinai Medical Center, in New York.

This was not necessarily a medical breakthrough—telesurgery has been performed successfully before—but rather a proof of principle that computer technology, robotics, fibre optics and surgical techniques have advanced sufficiently to overcome the technical problems that previously plagued the approach. Although still in its infancy, telesurgery is currently mainly used to train surgeons in endoscopic techniques and for consultations and telementoring. But in the long-term, experts expect it to be used on the battlefield, in space, in remote regions or in hospitals that lack a specialist to perform a complex operation.

While few surgeons are currently pondering adding telesurgery to their skills, many are in fact moving in that direction by adopting endoscopic techniques. Indeed, it was the development of endoscopy and laparoscopic surgery—keyhole techniques where surgeons insert remote-controlled instruments through small cuts—in the early 1990s that laid the groundwork for the development of telesurgery. Since laparoscopy requires a surgeon to manipulate instruments remotely, telesurgery means nothing more than further separating the tool and the controls by space and data-transmission technology.

According to Marescaux, the idea of telesurgery was born in 1993, after he had attended a lecture by a US military physician who envisioned its use on the battlefield and in space. He first collaborated

with European partners, but it became clear that their current technology was not compatible with the requirements of the operating room, mainly because data transmission via satellite would be too slow. He then started working with Yulun Wang, Chief Scientific Officer of Computer-Motion in Santa Barbara, CA, and developer of the company's Zeus robotic system, which was used for the operation in Strasbourg. Wang, who became interested in medical robotics in the early 1990s at the beginning of the laparoscopic boom, saw an opportunity to combine laparoscopy with telecommunications and robotics. He left NASA, where he was working at that time, and started developing a voice-activated robotic system.

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Telesurgery instrumentation is composed of five components, Wang explained. The first is robotic augmentation, or the surgeon's 'third arm' that moves the camera via voice controls. The second component is ergonomics to overcome the limitations of human anatomy. The robotic setup thus endows the surgeon with two 'left arms' if necessary and enhances flexibility, for instance by allowing an instrument to be rotated by 360 degrees. Thirdly, telesurgery should enhance the surgeon's natural dexterity. Fourthly, image support should be provided in order to guide the surgeon to a particular position on an MRI or CAT scan. Finally, telesurgery relies on fast and reliable data transmission between the surgeon and his or her tools and imaging systems. 'We are in the process of evolving all five elements to be better and to be used in various combinations for numerous applications,' said Wang.

Until September 2001, telemedicine specialists believed that 500 km was the limit for such procedures due to the time delay incurred by communication systems. But the New York–France telesurgery

overcame this limitation, and physicians were able to operate with a delay of less than 200 ms between the manipulation of the controls in New York and the action of the robot in Strasbourg. This was made possible by a high-speed data transmission system from France Telecom that linked all parts of the equipment—video camera, robot and telephone—by a transatlantic high-bandwidth fibre optic service of 10 Mbits per second.

The team first tested the system by conducting six laparoscopic gall bladder operations on pigs to identify and solve some problems, mainly concerning image clarity. The major test on a human patient, dubbed Operation Lindbergh after the pilot who took the first transatlantic flight, was a success. Marescaux and Gagner, working with physicians at the French Institute for Research into Cancer of the Digestive System, removed the gall bladder of the French patient in 45 min. She left the hospital after 2 days and recovered rapidly, her doctors reported. 'The demonstration of the feasibility of a transatlantic procedure constitutes a richly symbolic milestone,' said Marescaux. 'It lays the foundations for the globalisation of surgical procedures.'

Removal of the gall bladder was chosen as a model operation because it is relatively straightforward. However, robotically assisted laparoscopic surgery has successfully been performed on the oesophagus, kidney, bladder, stomach and spleen, according to Gagner. And its proponents see further potential for this new technology, mainly by improving the quality of existing techniques. 'The goal of minimally invasive surgery is more precise surgery,' Gagner said. Laparoscopy has already shown clear benefits for the patient, as the small incisions required reduce the risk of infection and complications and thus result in shorter healing times.

Indeed, robotically assisted endoscopy and telesurgery are the first technologies to have significantly improved surgical techniques in the last 200 years, according to cardiac surgeon Douglas Boyd MD, Director of Robotic Surgery at the Cleveland Clinic in Fort Lauderdale, FL.

'Our goals as cardiac surgeons are to limit the size of the incision, and to operate on the beating heart,' he said. The use of the heart–lung machine, while making surgery on the open heart possible, comes with a price: about 30–40% of patients suffer from neurocognitive deficits following their procedures. Boyd is the first surgeon to have used robotics and endoscopy to operate on a beating heart. Instead of making a long incision and cracking the ribs to access the heart, Boyd operates on a closed chest, with four pencil-width incisions to insert the instruments. A longer cable enables a surgeon to be 80 feet away, and with fibre optics, 80 miles away, he said.

Boyd also stressed that robotically assisted surgery is actually more accurate and uniform than conventional surgery, not only because of the ergonomic advantages outlined previously, but also because it allows high magnification of the surgical area, voice-activation of movements of the instruments and filtering out of tremors. The latter is a drawback in manual endoscopy because a physician's normal slight tremor becomes magnified, according to Boyd. Thus, surgeons using robotic 'hands' have far greater dexterity and precision—especially when operating in a small 'keyhole' space. Each movement is analysed by a motion sensor 1300 times per second, and verified by three computers, allowing surgeons to work beyond human limitations. 'It allows a good surgeon to be a great surgeon,' Boyd said.

Furthermore, telesurgery also has the potential to overcome infrastructure bottlenecks, mainly in developing nations where the nearest expert may be hundreds of kilometres away. Telesurgery would thus give patients a better chance of a satisfactory outcome without the need to send a surgeon to a remote hospital. 'It is known that results of CABG [cardiac bypass] surgery vary dramatically depending on whether a skilled surgeon performs the procedure,' Marescaux gave as an example.

He also named another benefit that he described as 'telecompanionship'. As surgeons typically do 20–50 operations

on patients while still in the learning process, 'this puts patients at some risk,' he said. Add to this the fact that every 2 years or so surgical techniques change, then there is obviously the need to provide surgeons with the opportunity to oversee other experts at work. That was actually the reason why Louis Kavoussi, Professor of Urologic Surgery at Johns Hopkins School of Medicine, started using minimally invasive urological surgery in the early 1990s for cancer, renal transplants, renal obstruction and testicular cancer. 'I became involved in telesurgery because my department felt that I was doing too much travelling in teaching these new techniques,' Kavoussi said. Unlike Operation Lindbergh, Kavoussi's system is 'home-based' and uses ISDN phone lines, audio, video communication, two cameras and X-ray images with the robot in the operating room. Kavoussi uses it for teaching endoscopic techniques and believes that it is far more effective than surgeons learning a new technique via a weekend course.

Until recently, the technical challenges of telesurgery have been to overcome time delays due to distance, cost, bandwidth and the transmission of sharp images. But this has all come with a price tag. Indeed, critics maintain that the procedure is simply unaffordable, pointing to Operation Lindbergh's cost of more than €1 million. And what happens in case of technical failures—if phone lines, the robot or other equipment fails? It would still require a second team of surgeons in the operating room in case of complications, maintains Ferdinand Köckerling, Chief Physician at the clinic Hanover Siloah in Hanover, Germany, who criticised telesurgery as 'unrealistic playing' in the German news magazine *Der Spiegel*. There are also the potential legal challenges, Boyd and Kavoussi conceded. Who is liable if something goes wrong? What if the performing surgeons are not licensed for out-of-state medicine? The US Food and Drug Administration only allowed Operation Lindbergh to be conducted by French surgeons for a French patient provided

France took all the responsibility. And resolving legal issues for use in the USA is likely to take a number of years, Marescaux observed. Currently, some form of telesurgery is being done in a number of other nations, including Austria, Germany, Italy, Singapore and Brazil.

But despite these obstacles, Wang is confident that telesurgery will become common practice. Currently, about 28% of operations are performed with laparoscopy, and this number is expected to grow. And as more surgical procedures adapt to this approach, a great deal of growth can be expected in the area of telesurgery, Wang thinks. Interestingly, practitioners such as Kavoussi and Boyd have not experienced opposition from patients, but rather the reverse. If using telesurgery means that there is an extra set of hands and eyes, and the participation of an expert in surgery, that is viewed positively by patients, Kavoussi said. And as second- and third-generation robotics are developed and telecommunication improves, the cost of telesurgery is also expected to drop.

At the same time, the general growth in telemedicine is also paving the way for telesurgery. The use of remote monitoring devices for heart disease and diabetes is increasing in hospitals and in out-patient care as well as the use of data links in and between hospitals. The Royal Society of Medicine in London, UK, recently held a meeting on telemedicine where the speakers reported excellent results using teleconferencing to treat patients with severe mental illnesses in remote areas, increase drug compliance or establish a distance-learning system for persons with disabilities. And as the use of telecommunications in medical care is becoming more widespread in Europe and North America, telesurgery is only a small step further. 'Many people view "globalisation" in negative terms,' said Marescaux. 'Telesurgery is one very positive effect of globalisation.'

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