Robotics and new technologies in surgery

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At the end of the 20th century, laparoscopic surgery has become a major turning point and has marked the beginning of the Information Age revolution for surgery. But minimally invasive surgical procedures, considered to be the greatest technological advancement in recent years, is only the tip of the iceberg. It should be considered as a transition technology from the era of open surgery to the new era of Computer Assisted Surgery (CAS), such as robotic surgery, telesurgery, virtual reality, image guided surgery or augmented reality.

Past and Present
In centuries past, technology had appeared in a slow and measured fashion, with a predictable linearity, allowing the medical community to assimilate the changes. However, the recent trend of technology development has been following an exponential growth, especially in the information technologies of computers and communications. This accelerated growth is stimulated by a concomitant development in technology transfer, manufacturing and commercialization. Never in the past have new ideas or inventions been brought to product stage so quickly and distributed so widely. Without the help of biomedical engineers, it has become difficult for the surgeons to understand in details the workings and the implications of these new technologies. However, this understanding is primordial so as to have the capacity for an adapted and safe use, especially under the commercial pressure of the manufacturer.

The Information Age in surgery began with laparoscopic surgery because for the first time, the surgeon no longer looked directly at the patient’s organs but rather at the video monitor where the electronic image (information equivalent) represented the organs. This digital state affects all the fields of medicine. The radiological studies are changing from films to digital images accessible from any computer through out the network. In the future, Virtual Reality (VR) will replace cadavers for teaching anatomy. VR simulators will allow young surgeons to train procedures safely without the need of animals or the presence of an expert, with automatic evaluation of the performance and identification of the errors.

Robotics and Remote Surgery
Even if robots have been used for a long time in industrial processes, it is more recent in the health field. A surgical robot can be defined as an informatic system composed of a motorized arm controlled by a computer to move instruments and perform surgical gestures. There are two kinds of robots. Simple ones are positioning systems as the AESOP® system (Computer Motion) used as a camera holder (see picture). It is controlled by voice activation. Complex robots are composed of two sub-systems. The first one is the human-machine interface and is considered as the master part. The second one is the telemotor system holding the instruments and is considered as the slave part. The surgeon is sitting at the master console manipulating handles to perform the surgical procedure. The robotic arms of the slave module are in direct contact with the patient, holding the instruments inside the patient’s body and reproducing with high precision the movements performed by the surgeon.

Robotics and telesurgical systems are information systems because hand motions are converted to electronic signals which are sent to the surgical effectors. This digitalization of the motion has several advantages, especially on precision of the gesture and ergonomics. In laparoscopy, long and rigid instruments are used through trocars placed in the body wall. This situation amplifies physiologic tremor, creates the fulcrum effect (inverted movement between the surgeon’s hand and the instrument tip, creating a disparity between visual and proprioceptive feedback) and limits internal movements of the instrument tip to four degrees of freedom. To allow free motion in a three-dimensional space, robotic instruments have six degrees of freedom due to the articulation at their extremity. This is particularly useful to perform complex movements in difficult areas. Computer processing and filtering of the movements suppress the hand tremor, eliminate the fulcrum effect and reduce the scaling of the motion improving the dexterity and the precision. This is particularly useful for microsurgery.

In laparoscopy, the surgeon is operating beside the patient. Trocars positioning is always a compromise between the best placement for the surgical target inside the body and the ergonomics of the operator. The digitalization of the motion and the master-slave configuration of the robot allow a separation between the surgeon and his patient. With the robotic system, the surgeon now has better ergonomics. Sitting in a chair with his forearms lying stable and with correct positioning of the 3D monitor, all of which decrease physical workload without conflicts of interest for the trocars placement. But there are some unsolved disadvantages. Due to the lack of force-feedback control and tactile sensitivity, it is very difficult to modulate the application of force on the tissue. For now, this control is usually performed only by visual control. New generations of robotic systems will include tactile-feedback to correct this drawback.

Telesurgery offers new possibilities
In addition to enhancing human performance, robotic systems provide the unique ability to perform surgery in remote locations. With this possibility to have a distance between the surgeon and his patient was born the concept of telesurgery or remote surgery. This concept was first investigated by the NASA in the late 80’s in order to perform remo-
Te surgical operations in space. Telesurgical robotic systems were next developed on the impulsion of the US army in the beginning of the 90's. The aim was to improve medical support of the military on the battlefield. The concept was to have the wounded soldier operated in an armored vehicle at the battlefield front by a surgeon operating from a safe area. Te major problem with remote surgery is the latency, the time delay between the hand motion initiated by the surgeon and the remote manipulator actually moving and the return image on the surgeon's monitor.

Based on several experiments, it has been demonstrated that about 300 ms is the maximum time delay compatible with the safe performance of surgical manipulations. Due to this latency factor, it was believed that the feasible distance for remote surgery was no more than a few hundred kilometers with terrestrial telecommunications. Geosynchronous satellite systems, which have a latency of nearly 1.5 seconds, are considered unsuitable for performing long-distance surgery. On the 7th of September 2001, J. Marescaux1,2 and his team performed successfully a robot-assisted laparoscopic cholecystectomy between New York (USA) and Strasbourg (France) on a 68 year-old woman with the Zeus™ system (Computer Motion) using the transatlantic asynchronous transfer mode (ATM) fiberoptic network (bandwidth of 10 Mb/s). Despite a round-trip distance of more than 14,000 km, the mean time lag for transmission during the procedure was 155 ms. Te surgeons perceived the procedure as safe and the overall system as perfectly reliable. Remote surgery is a real program in development in Canada for example, where these means of operating could be cheaper than moving patients to adequate hospital thousand kilometers away from home. However, what use can we have in Switzerland where the geographical situation is totally different and hospitals so close at hand? Te possibility of having active interventions from remote locations opens the route for surgical education for new practitioners from remote locations opens the route for surgical education.

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References

Current research explores the fields of automation with robots filtering unwanted parasite movements and automatically bringing instrumentation into the operative field. It is easy to understand the interest of having the robotic arm following automatically the movements of the organ – as a heart beating during a coronary bypass – allowing the surgeon to perform the procedure as if the field was totally stable. Now is only the beginning of the revolution of new technologies in surgery.

This escalation of technologies developed for surgery has direct implications for the surgical community to avoid lagging behind and loosing the power of self-arbitrary decision for the future. Academic hospitals have the duty and the responsibility to be strongly involved in the evaluation of these new technologies to validate scientifically the possibilities and the indications of use. Other aspects have to be solved, such as moral, ethical, safety, political and economical considerations. However, we have to keep in mind that technology is neutral: it is neither good or evil. Technology is just how we use it. It is up to us to use it with ethical consideration for our patients.

Virtual Reality and the Future
Apart from robotics, the use of VR based on reconstructions of patient-specific data from CT or MRI studies into full 3D models has provided new tools for diagnostic, preoperative planning, surgical simulation and intraoperative navigation. These softwares, as the one developed by the IRCAD in Strasbourg (France), enhance anatomical and pathological 3D vision of the patient, improving diagnostics and surgical planning, especially for complex procedures. Integration into surgical simulators allow safe training for surgeons as do flight simulators for pilots. If intraoperative navigation for stereotaxic image-guided surgery is already used in neurosurgery for example, the next step will be the use of real time augmented reality (the superimposition of VR images onto the real patient) into the operating room during the procedure giving the capacity to see through the patient. The fact that an image in a monitor is used to see the patient allows the possibility to merge this image view with other informations such as 3D reconstructions. With this help, surgeons will know in advance where are the anatomical structures before it is possible to see them, improving preciseness and safety. The current limitation in general surgery is the real time synchronization with the respiratory movements.

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