Telesurgery – Trends Including Robot-assisted Technology

a report by

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Significant interest and enthusiasm is rising over robotic and computer-aided surgery and about telesurgery in general, but what can we expect from the application of new technologies to surgical practice in the future?

Robot-assisted Surgery

Robotic Enhancement of Dexterity and Clinical Applications

With the introduction of robotic and computer technologies to surgical operations, surgical movements and images could, for the first time, be digitised and transmitted. This information can be modified to filter and exclude non-finalised movements (i.e. the physiological tremor of the surgeon),[1] resulting in greater dexterity and higher precision.[2–3]

Robotic devices that cancel physiological tremors have been used for vitroretinal microsurgery;[4] others have reported efficient performance of sutured coronary artery bypass anastomoses in a plastic model using robotic enhancement technology.[5] Although, admittedly, there are fewer instances where such a higher degree of precision is needed in general surgery operations, robotic assistance has been used successfully for a large variety of procedures. Laparoscopic robotic cholecystectomies have been performed on 25 patients with no robot-related morbidity and with operative time and patient recovery similar to those of conventional laparoscopy.[6] Cadiere and coworkers have reported on robot-assisted laparoscopic antireflux procedures, gastroplasties, inguinal hernias and prostatectomies.[7] Falcone, et al. reported successful robotic assistance for reversal of tubal ligation using 8–0 sutures.[8] In these published experiences, there was no morbidity related to the use of the robotic system; however, there is a common feeling that robotic assistance is most beneficial when microsuturing within the abdomen or in very confined spaces.

In cardiac surgery, robotic systems have facilitated performance of endoscopic coronary artery bypass and mitral valve repair.[9] It is known that the post-operative patency rates of coronary bypass grafts range from 65% to 100%,[3] and robotic assistance may possibly help to narrow this range.

Remote Telesurgery

Through telecoms lines, digitised information can be

1. *A Garcia-Ruiz, M Gagner, J H Miller, C P Steiner and J F Hahn, "Manual vs robotically assisted laparoscopic surgery in the performance of basic manipulation and suturing tasks",* Arch. Surg., *133 (1998), pp. 957–961.*
2. *R J Damiano, Jr, et al., "Initial United States clinical trial of robotically assisted endoscopic coronary artery bypass grafting",* J. Thorac. Cardiovasc. Surg., *119 (2000), pp. 77–82.*
3. *H Reichenspurner, D Boehm and B Reichart, "Minimally invasive mitral valve surgery using three-dimensional video and robotic assistance",* Semin. Thorac. Cardiovasc. Surg., *11 (1999), pp. 235–240.*
4. *M Gomez-Blanco, C N Riviere and P K Khosla, "Intraoperative tremor monitoring for vitreoretinal microsurgery",* Stud. Health Technol. Inform., *70 (2000), pp. 99–101.*
5. *A Garcia-Ruiz, N G Smedira, F D Loop, J F Hahn, J H Miller, C P Steiner and M Gagner, "Robotic surgical instruments for dexterity enhancement in thoracoscopic coronary artery bypass graft",* J. Laparoendosc. Adv. Surg. Tech. *A, 7(5) (1997), pp. 277–8.*
6. *J Marescaux, M K Smith, D Folscher, F Jamali, B Malassagne and J Leroy, "Telerobotic laparoscopic cholecystectomy: initial clinical experience with 25 patients",* Ann. Surg., *234 (1) (2001), pp. 1–7.*
7. *G B Cadiere, J Himpens, O Germay, R Izizaw, M Degueldre, J Vandromme, E Capelluto and J Bruyns, "Feasibility of robotic laparoscopic surgery: 146 cases",* World J. Surg. *(2001) (in press), published online.*
8. *T Falcone, J M Goldberg, H Margossian and L Stevens, "Robotic-assisted laparoscopic microsurgical tubal anastomosis: a human pilot study",* Fertil. Steril., *73 (5) (2000), pp. 1,040–2.*
9. *A LaPietra, E A Grossi, C C Derivaux, R M Applebaum, C D Hanjis, G H Ribakove, A C Galloway, P M Buttenheim, B M Steinberg, A T Culliford and S B Colvin, "Robotic-assisted instruments enhance minimally invasive mitral valve surgery",* Ann. Thorac. Surg., *70 (3) (Sep. 2000), pp. 835–8.*

transmitted to distant locations, enabling surgeons to operate on patients located remotely. Challenges to this concept are several, but the most important limitations have been the reliability (or quality of service) of the telecoms lines and the issue of latency (the delay time from when the hand motion is initiated by the surgeon until the remote manipulator actually moves and the image is shown on the surgeon's monitor). Preliminary studies estimated at about 300msec the maximum time delay compatible with safe performance of surgical manipulations, and a mean time delay was measured of 155msec over transoceanic distances[10] when using dedicated asynchronous transfer mode (ATM) fibres. On 7 September 2002, the world's first human long-distance operation was performed, demonstrating the feasibility and safety of performing a complete surgical operation from remote locations.[11]

Currently, there are several limitations for routine performance of remote telesurgery, such as the lack of a network of ATM lines between hospitals, the costs and ethical and medico-legal aspects. In particular, there is still a lack of internationally agreed regulations for medical practice. Potential benefits of remote robot-assisted surgery, however, are multiple. The most evident is that geographical constraints will no longer determine the type of treatment the patient receives. Ideally, any patient can receive the treatment most appropriate or advantageous for his/her condition. Telesurgery may have an even more profound impact on developing countries or on emergency operations in small rural hospitals, which are sometimes challenging for young surgeons on call.

The possibility of having active intervention from remote locations also opens new avenues for surgical education. Telesurgery can, in fact, significantly improve outcomes through teaching and mentoring in order to reduce the learning curve of surgeons for new procedures, thus possibly helping to standardise surgical care worldwide. Telesurgery could also be an opportunity for cost savings. For instance, it has been estimated that between 44,000 and 98,000 deaths occur annually due to errors in hospital care and that as much as 54% of surgical errors could be prevented.[12] Through the ability to provide active intervention of remote experts, robotics may well reduce the learning curve effect on errors and reduce morbidity and its related costs. Many surgical procedures still depend on the operator's skills and experience and the learning curve significantly influences outcomes. One example is rectal cancer surgery, where it has been demonstrated that the surgeon's skills and experience represent the most important prognostic factor.[13]

The Impact of Virtual Reality Technologies in Telesurgery

Implementation of virtual reality and simulation in surgical practice may create additional and significant opportunities to improve surgical care.

Virtual Reality, Surgical Education and Training

Virtual reality provides a safe training environment where errors can be made without consequences to a patient. The learning process is based on understanding the cause of failure. Virtual reality can be used to improve the teaching of surgical anatomy, in particular when dealing when the inner anatomic structure of a complex and non-transparent organ such as the liver.

An additional advantage of virtual environments and computer-based surgical simulators is that these systems are capable of tracking continuously the hand motions as well as the trainee's actions, allowing for realtime monitoring and display of the student's skills. Skills, as well as precision and appropriateness of the student's actions, can therefore be analysed to monitor an individual's improvement. Virtual reality can be used to communicate with and teach trainees in distant locations. Silverstein, et al.[14] used a teleimmersive virtual reality environment for simultaneously teaching liver segments and portal vein anatomy to senior surgical residents at two different locations. Effective acquisition of the new knowledge was reported with no difference between those residents who were with the instructor and those at the remote location. This was assessed by a 24-question examination test administered before and after the anatomy workshop.

In the end, the opportunities afforded by virtual reality and simulation may improve the level of surgical education and result in better quality of surgeons' healthcare.

10. *J Marescaux, J Leroy, M Gagner, F Rubino, D Mutter, M Vix, S E Butner and M K Smith, "Transatlantic robot-assisted telesurgery",* Nature*, 413 (6,854) (2001), pp. 379–80.*
11. *J Marescaux, J Leroy, F Rubino, M Smith, M Vix, M Simone and D Mutter, "Transcontinental robot-assisted remote telesurgery: feasibility and potential applications",* Ann. Surg.*, 235 (4) (2002), pp. 487–92.*
12. *L T Kohn, J M Corrigan and M S Donaldson (1999),* To err is human: building a safer health system*, Washington, DC: National Academy Press.*
13. *C S McArdle and D Hole, "Impact of variability among surgeons on postoperative morbidity and mortality and ultimate survival",* BMJ*, 302 (6,791) (1991), pp. 1,501–5.*
14. *J C Silverstein, F Dech, M Edison, P Jurek, W S Helton and N J Espat, "Virtual reality: immersive hepatic surgery educational environment",* Surgery*, 132 (2) (2002), pp. 274–7.*

Virtual Reality for Preoperative Simulation and Intraoperative Aid

A further application of virtual reality is the preoperative simulation and planning of robot-assisted procedures. Combining virtual laparoscopy with a virtual ZEUS robotic system, there may be the possibility of simulating the surgical gestures required for a specific procedure in a given patient with a system that is able to process this information.

Augmented reality is a technology that allows superimposing computer-generated images on the real vision of the world in realtime. Thus, the three-dimensional (3-D) reconstruction can be superimposed on the real patient to provide additional guidance and to make inner structures visible on the surface of the skin or the liver, for example. The European Institute of Telesurgery (EITS) has developed its own realtime augmented reality system for hepatic surgery. Two cameras provide a 3-D video view of the physical model. By superimposing the virtual model, a virtual transparency of the physical model is obtained. Images are then displayed on a head-mounted displayer that combines the virtual and real images. Augmented reality has been used preliminarily with promising results in experimental simulation of radiofrequency ablation in both plastic and animal models.

Telemedicine, Telesurgery and Virtual Reality

Using telecoms technology, virtual patients' data can be shared in realtime with colleagues at remote locations – for educational purposes as well as for obtaining active consultation of other specialists. The EITS has recently verified the feasibility of this kind of application of virtual reality. In a project called 'Argonaute',[4] different centres in France were connected simultaneously through the Internet, sharing the virtual reconstruction of a patient with liver metastasis. The patient's case was presented allowing not only interactive realtime discussion of the most appropriate management's strategy, but also preoperative planning of radiofrequency ablation of a left-sided liver metastasis. Surgeons from the different centres could access the patient reconstruction easily and even move a virtual needle to simulate a radiofrequency ablation through the use of a simple computer mouse. This application of virtual reality and telesurgery might prove valuable for surgeons by allowing discussion of difficult cases, obtaining expert assistance in realtime for the decision-making process, as well as for assisting in the planning of the operation. Likewise, this kind of application can be an important tool for surgical education. ■