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Telesurgery: Remote Knowledge Translation in Clinical Surgery

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Abstract Dissemination of new surgical knowledge, skills, and techniques across the wide spectrum of practicing surgeons in the community is often difficult and slow. This is even more problematic in countries such as Canada, where geographic distances separate a large portion of community surgeons from the large teaching centers. As an example, the penetration of advanced minimally invasive techniques in Canada has been severely hampered by the inability to provide adequate training opportunities and support for community surgeons, many of whom live in remote regions of the country. In an attempt to overcome the barriers that exist, the Centre for Minimal Access Surgery (CMAS) at McMaster University has been using broadband Internet and telecommunication systems to provide distance training and mentoring to community surgeons living in remote northern communities of Canada. This article describes our experience with telementoring and robot-assisted remote telepresence surgery and assisting, between a teaching hospital in Hamilton and two community hospitals in northern Ontario and Quebec.

Almost two decades have passed since the start of the laparoscopic revolution with the performance of the first series of laparoscopic cholecystectomies. Although laparoscopic and other minimally invasive techniques have now been applied to a wide range of surgical procedures with demonstrable success, the level of penetration of these techniques remains comparatively low across the world. In the first decade, lack of long-term results was a factor in adoption of such techniques. However, at present the most important reason for lack of penetration of minimally invasive techniques is the inability of the surgical community to translate the necessary knowledge and skills to the vast number of surgeons in the community. This failure to meet the demand for training has led many investigators over the last two decades to evaluate new technology in bridging the knowledge gap that exists with the advent of such important paradigm shifts.

The only proven technique of teaching surgeons new skills is one-to-one on-site mentoring complemented with hands-on course training and conferences. Such one-to-one training presents significant challenges, however, when there is a small pool of recognized experts and a large number of surgeons in need of training. Inherent in such a system is the time wasted in travel from one site to another and an inability to train more then 1–2 surgeons at each site at any one time. It is also difficult to provide longitudinal ongoing support as the trainee gains experience and begins to tackle more complex cases. These challenges are even more acute in countries like Canada, where community surgeons are spread out in vast and dispersed corners of a large subcontinent, and where a mentor may be required to travel hundreds or thousands of miles to offer training to a surgeon in an isolated community. Specific geographic situations in Canada have already led to the rapid adoption of telemedicine, supported by investments from the provincial governments in appropriate telecommunication connectivity to hospitals and clinics in even the most remote parts of the country. Such investment has made Canada an appropriate environment to develop and evaluate new techniques in knowledge translation in the form of telementoring and telerobotic-assisted surgery. In fact, at this time, Canada is the only country where telerobotic remote surgery has been used clinically to offer advanced laparoscopic procedures to patients in small community

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hospitals; in the process it has enabled local surgeons to acquire advanced laparoscopic skills from experts in a tertiary hospital.

This article describes the experience with telementoring and telerobotic surgery over the last decade through the Centre for Minimal Access Surgery (CMAS) based at McMaster University and St. Joseph's Hospital in Hamilton, Ontario. It also describes the challenges facing wide adoption of tele-surgery and future directions in research.

The Centre for Minimal Access Surgery was created in 1998 to meet the ever-increasing demand for further training in advanced laparoscopic procedures. To augment its regular hands-on courses, the Centre initiated a telementoring program in 1999, and in 2003 initiated its telerobotic surgical program with great success.

CMAS telementoring program

Telementoring relies on two-way video conferencing to transmit live laparoscopic image from the mentee's site (usually a community hospital in northern Canada (Fig. 1) to the mentor (expert surgeon), based at CMAS. The mentor is thus capable of watching and providing real-time advice and instructions, aided by a telestrator (Fig. 2). Several previous studies have validated the effectiveness of telementoring in knowledge translation during live surgery [1–9]. Prior to participating as a mentee in the CMAS telementoring program, surgeons complete a hands-on training course in laparoscopic techniques followed by one-on-one mentoring by a CMAS faculty member for a minimum of two cases. During this on-site mentoring, the faculty member travels to the remote hospital to assess the surgeon's skills in performing the procedure, as well as the ability of the local hospital to provide both the equipment

Fig. 1 Dr. Trudeau and team in Chicoutimi, Quebec, being telementored by a surgeon mentor from the Centre for Minimal Access Surgery (CMAS) at Hamilton, Ontario

Fig. 2 The CMAS telementoring office with Telestrator

and professional support necessary in the performance of such procedures. Once the mentoring surgeon is satisfied with the mentee's knowledge and basic two- handed skills, as well as with the hospital's resources, the mentee is offered the opportunity to participate in further training sessions in the form of two-way video conferencing.

Over a period of 9 years, CMAS has offered over 100 sessions of telementoring to almost one dozen surgeons in rural communities in Northern Ontario and Quebec. The effectiveness of this telementoring program has been formally assessed and published in peer reviewed journals [10, 11]. A number of factors have been determined to be essential in ensuring effectiveness and safety of telementoring. The most significant of these is the clarity of the video and audio signal available to the mentor.

We encountered a number of challenges during this experience and many important lessons were learned.

1. Telecommunications bandwidth. In our experience, a bandwidth of 512K was sufficient to allow safe and effective telementoring. Although we were able to go down to 384K at times [12], anything less than this was thought to be too dangerous to complete the telementoring.
2. Telecommunications latency. In general, latency was not found to be a significant factor during the CMAS telementoring experience. On average, latency of the networks used ran between 200 and 350 ms. Telecommunication evaluations following each case showed that neither the mentors nor the mentees felt that this amount of latency interfered with effective telementoring.
3. Adequate telecommunications infrastructure. Most centers in Canada possess reasonable telemedicine infrastructure. Centers which were keen to perform regular telementoring were advised to purchase a

suitable system for their operating room. The ideal system is able to transmit two channels of video and audio. The average cost of such a system at the time was approximately $10,000 to $15,000. The cost of transmission of video and audio signals on the IP/VPN network connecting the hospitals is free in Canada, but at times a bridging company had to be used to connect between provinces, and thus a minimal cost was encountered.

4. Medico-legal liability. This has traditionally been a major barrier to telementoring, since surgeons are participating in procedures across provincial/state, national, and even international boundaries. The Canadian situation is rather fortunate in that the Canadian Medical Protective Association (CMPA) covers a physician for any medical acts throughout the country, provided that the physician is adequately licensed and privileged in the local institution. To ensure that this condition was met, every telementor had to be licensed in the province of the trainee, and appropriate privileges were obtained from the local hospital where the surgery was being performed.
5. Ethical issues. Patients were fully informed of the process of telementoring and were given the opportunity prior to the surgery to consult with the expert surgeon via teleconsultation to address any possible questions. They were also informed that in the event of a telecommunication failure, the local surgeon would either complete the procedure laparoscopically if possible, or would convert to an open procedure.
6. Lack of physicality. The last and final challenge associated with telementoring is the lack of physicality for the mentor. The inability of the mentor to assist and step in when necessary during a telementoring session is considered one of the major limitations of telementoring as compared to on-site mentoring. This led the group to evaluate the feasibility of using a remotely operative robot [13] to provide tele-existence for the telementor, allowing the mentor to assist or operate remotely to enhance the telementoring experience.

Fig. 3 The Telerobotic Room at CMAS, St. Joseph's Hospital, Hamilton, demonstrating Dr. Anvari performing surgery on a patient in North Bay using the Zeus TS System

Fig. 4 Dr. Craig McKinley assisting with telerobotic surgery, North Bay, Ontario. Dr. Anvari is controlling the Zeus TS arms remotely from Hamilton and performing remote telepresence surgery

Robotic-assisted remote telepresence surgery

In 2002 the group started to evaluate the use of a Zeus TS robot (Figs. 3 and 4) to perform telerobotic surgery using IP/VPN network, the primary mode of telecommunication between hospitals across Canada [13]. This network provides Quality of Service (QoS) and, through encryption, privacy, and security, is suitable for a variety of telemedical applications. However, in order to use telerobotic surgery we needed a minimum bandwidth of 10 mbps, double redundancies, and diversification of the network to ensure that we were able to deal with any conceivable network disturbance during a telerobotic surgery.

Between 2003 and 2005, we performed 22 robotic-assisted remote telepresence surgeries (RARTS) between CMAS, situated in Hamilton, and North Bay General Hospital, over 350 km away in northern Ontario. The details of the experience have been previously published [14, 15]. The surgeries were selected based on the training needs of the local surgeon and were completed as true collaborations between the two sites. The mentor was able to perform all or part of the surgery using the three-arm robot. The mentor was also able to assist the local surgeon during performance of the surgery and take over when necessary. The experience proved the clinical viability of RARTS, and was unfortunately halted with the dissolution of Computer Motion and the discontinuation of Zeus TS, the only commercial robotic platform capable of remote teleoperation.

Important lessons learned

Patient acceptance

Early in the experience, it became obvious that patients will accept the idea of a remote telerobotic surgery if they perceive that it is in their best interest. In our experience the fact that patients were able to receive advanced laparoscopic surgery in their own home community without having to be transferred to a tertiary hospital in another city, and still have the advantage of an expert's experience was desirable to all patients. In fact, no one who was offered telerobotic surgery refused it; in fact, many patients requested telerobotic surgery even when it was unnecessary. The 22 cases selected for telerobotic surgery were those in which the local surgeon thought there was a need for appropriate support, training and intervention by the expert laparoscopic surgeon.

Time delay

The time delay in telecommunication was an important factor in the surgeon's ability to perform complex tasks within the appropriate time frame and with an adequate level of accuracy [12]. We experienced time delays of 150–200 ms during most procedures but found that on occasions when the delay exceeded 250 ms, performing tasks telerobotically became slow and less effective.

Adequacy of systems

Telecommunication systems available today for telemedicine are adequate to meet the need of telepresence for most surgery as long as adequate quality of service, redundancy, and diversification are obtained.

Setting up and dismantling the system

The local surgical team needs to be comfortable with set-up and dismantling of the robot and will quickly become comfortable with the idea of telepresence surgery.

Remote expert surgeon's knowledge of the local operating room

The remote surgeon has use of large-screen TVs and good surround sound systems that allow easy communication between the remote surgeon and the local surgical team at the side of the patient.

Telesurgery in an extreme environment—the NEEMO missions

In 2004 CMAS embarked on a series of experiments in collaboration with NASA and the US military's TATRC division to evaluate the possibility of using telementoring and telesurgery to provide emergency medical and surgical care to an injured patient in an extreme environment. The NEEMO missions took place aboard the underwater research habitat Aquarius, which is located off the coast of Key Largo, Florida, and operated by the National Undersea Research Centre (NURC). Because the confined space and pressurized environment of Aquarius make it an excellent analogue for the conditions encountered during space missions, NASA uses the habitat to both train astronauts and evaluate new technologies. We were able to use this habitat for two joint missions—NEEMO 7 (October 2004, for 10 days) and NEEMO 9 (April 2006, for 18 days). For each mission, the crew consisted of 3 astronauts, 1 CMAS surgeon, and 2 NURC technicians. During these missions, we evaluated the use of telementoring for performing of a variety of diagnostic medical and surgical acts including ultrasound examination and x-ray acquisition, fixation of bone fractures, cystoscopy, suturing, and cholecystectomy. The NASA astronauts, several of whom had no previous medical training, were telementored while performing the selected tasks by expert surgeons and radiologists located at CMAS in Hamilton, Ontario. A combination of telecommunications links were used over the course of the two missions, including IP/VPN, regular broadband Internet and microwave transmission between the base in Key Largo and the Aquarius habitat 5 miles off shore. As well, during the NEEMO 9 mission, we evaluated the use of a portable new robotic platform (Fig. 5), developed by SRI international, in performing remote telepresence surgery between Hamilton and Aquarius using regular Internet lines. We also evaluated the impact of a 2-s time delay, which is the time delay experienced over the distance be-

Fig. 5 Setting up the M7 in the Aquarius. Left: Ron Goran, NASA Astronaut. Right: Jim Buckley, NOAA/UNCW Aquarius Program

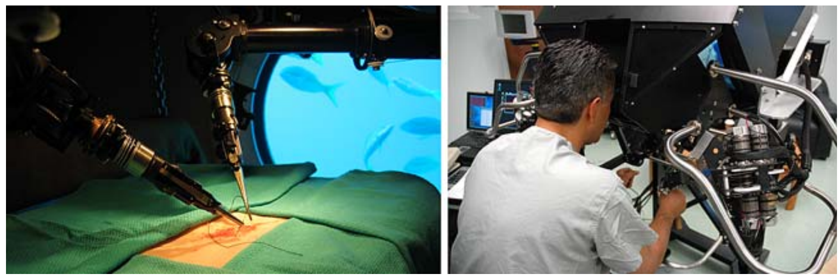

Fig. 6 Performing telerobotic surgery during the NEEMO mission

tween earth and moon, on both telementoring and telesurgical tasks.

During these missions we established [16] that telementoring was an effective tool in translation of knowledge to allow a physician to perform emergency diagnostic and surgical tasks even with transmission time delays of over 2 s. We also successfully tested the viability of a portable robotic platform to allow a remote surgeon to perform a simple emergency surgical task on injured patients in an extreme environment [17]. However, telerobotic surgery at a 2-s time delay was clinically not feasible (Fig. 6). As a result of this experience, CMAS is collaborating with a number of centers and companies to develop automated robotic tasks to overcome such significant time delays.

Conclusions

Our experience in the last decade with telementoring and telerobotic surgery has demonstrated that, with the adoption of new telecommunication technology, we are able to translate knowledge rapidly and effectively across large distances. The use of telementoring and telerobotic surgery will one day become routine, and will revolutionize the way new technologies and techniques are spread throughout the surgical world and across national boundaries. In the meantime, significant investment is necessary to improve the current robotic technology as well as overcome some of the international and even national boundaries to such practices, such as lack of national licensing and, in many countries, lack of national insurance plans to cover such medical acts. The adoption of these technologies will require an assertive global effort and will one day reduce the knowledge gap that exists around the globe.

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