Main Topic: Telesurgery

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Reaching the rural world through robotic surgical programs

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Stellenwert von Telechirurgie und Robotertechnologie für die chirurgische Versorgung in entlegenen, ländlichen Regionen

Zusammenfassung. *Grundlagen:* Bewohner ländlicher, entlegener Regionen haben nur beschränkten oder keinen Zugang zu moderner, hochentwickelter chirurgischer Versorgung. Mittels Teleunterweisung und telechirurgischen Netzwerken könnte das Wissen chirurgischer Spezialisten von städtischen Zentren in entlegene Regionen gebracht werden.

Methodik: Literaturübersicht.

Ergebnisse: Telemedizin stellt ein effizientes Werkzeug dar, um den in entlegenen Regionen tätigen Chirurgen zu unterstützen und auszubilden. Erste Erfahrungen zeigen, dass Chirurgie mittels Telemedizin sicher an Patienten in entlegenen Regionen durchgeführt werden kann. Trotzdem müssen noch technische, ethische und rechtliche Aspekte geklärt werden.

Schlussfolgerungen: Mit der Entwicklung von Telekommunikation und Robotertechnologie wird die Telechirurgie zunehmend an Bedeutung für die chirurgische Versorgung von Bewohnern ländlicher, entlegener Regionen gewinnen, denen eine solche Therapie mangels eines entsprechenden Spezialisten vor Ort nicht zur Verfügung steht.

Schlüsselwörter: Teleunterweisung, Telechirurgie, chirurgischer Roboter.

Summary. *Background:* For patients living in rural and remote areas, access to advanced surgical care is frequently limited or even nonexistent. Establishment of telementoring and remote telesurgical networks would enable patients in these areas to benefit from the knowledge of expert surgeons in distant urban centres.

Methods: Literature review and personal experience.

Results: Telementoring provides a convenient and effective means for community surgeons to learn new surgical techniques. Although still in its infancy, initial experience with routine clinical use of remote telepresence surgery indicates that it can be used to safely offer surgery to patients in a rural community. However, a number of technical, ethical, and legal challenges still exist.

Conclusions: As telecommunications and robotic technology evolve, remote telesurgical programs will play an increasing role in providing high-quality surgical care in rural communities and may even facilitate emergency surgical care in remote areas in the absence of a local physician.

Key words: telementoring, remote telepresence surgery, surgical robotics.

Introduction

With the development of laparoscopic techniques, surgery has begun to move into the information age. Laparoscopic instruments allow surgeons to operate without direct physical contact with the patient's relevant anatomy. Furthermore, the video displays used to observe the operative field allow detailed images of procedures to be transmitted outside of the OR, facilitating both collaboration and education.

However, despite a number of advantages for patients, including shorter hospital stays and more rapid return to normal activities, it is widely believed that laparoscopic surgery is a transitional technology that will eventually give way to computer-assisted techniques, including image-guided and robotic surgery [1]. Control of laparoscopic instruments via robotic master–slave systems overcomes many of the disadvantages of laparoscopic surgery, including poor surgeon ergonomics, loss of three-dimensional visualization, tremor amplification, and the fulcrum effect [2]. Furthermore, surgical telemanipulators are capable of enhancing precision and dexterity, thus allowing surgeons to perform procedures beyond the limits of conventional laparoscopy. While clinical use of current telesurgical systems involves the surgeon ma-

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nipulating the robotic arms from a console located close to the patient, two groups to date have demonstrated that these systems can successfully be manipulated over substantial distances via telecommunications links [3, 4]. Further development of this technology has the potential to dramatically change the delivery of surgical services in rural areas and in developing regions of the world, allowing patients in these underserviced areas to benefit from the experience of expert surgeons in major urban centres. Currently, those people living in rural areas must travel to a tertiary care centre far from their family and friends for most advanced surgical procedures. In cases involving critically ill patients, transfer to a larger centre may result in added complications or even death. For people living in remote regions, especially in developing nations, access to surgical care may be virtually nonexistent. The development of programs that would allow expert surgeons to reach patients in distant locales through tele-existence would alleviate many of the current inequities in the delivery of surgical care by bringing the surgeon to the patient instead of the patient to the surgeon.

Although the concept of remote telesurgery generates the most interest and speculation, surgical care begins long before the patient enters the OR and continues long after they leave. Development of a comprehensive telemedicine program for surgery will require a multimodality approach. Such a program could include teleconsultation for patient screening, transmission of preoperative imaging studies and investigations, as well as postoperative follow-up via videoconference. Telementoring, both with and without the use of remotely controlled robotic devices, has already been shown to be a powerful tool for knowledge transfer [5, 6]. It allows expert surgeons to advise, demonstrate key steps, and even manipulate a single robotic arm over long distances and is being used to allow surgeons to safely master new techniques without the need to travel to distant teaching hospitals.

Despite showing great promise, telesurgery has a number of obstacles to overcome, both technical and nontechnical. Current surgical robotic systems have major drawbacks that limit their use for remote applications. Also, while videoconferencing and other telemedicine applications can use low-bandwidth communications, remote telepresence surgery requires access to the latest high-bandwidth connections. While these are becoming increasingly available and affordable, there are still many areas of the world with no access to modern telecommunications networks. Telesurgical programs also pose a number of challenges related to licensing across political boundaries, development of standards and guidelines, assessment of liability, patient consent, and confidentiality of electronic health records. In addition, as is the case with all telemedicine programs, telepresence surgery will have to demonstrate through clinical evaluation its effectiveness and long-term financial viability if it is to gain widespread acceptance.

Potential for telesurgery programs to reach rural populations

Remote telesurgical programs have the potential to benefit patients in rural communities, the community surgeons who practice there, and the healthcare system in general through improved access to surgical care, greater opportunities for continuing education, and reduced need for patient transfer.

For patients living in rural areas, undergoing advanced surgical procedures often involves leaving their communities and the support of family and friends in order to receive care at a tertiary care centre far from home. Typically, multiple trips are required for preoperative consultations, clinical evaluations, and postoperative follow-up. For more routine procedures, patients might also be faced with a choice between having a minimally invasive procedure at a distant facility or having a more invasive open procedure performed at a local hospital. The development of telesurgery networks that enable expert surgeons to share their knowledge with local community surgeons either through telementoring or remote telepresence surgery would allow patients in rural areas to receive higher quality surgical care without leaving the community.

In cases involving trauma or emergency surgery, such networks also have the potential to save lives by reducing the discrepancy that currently exists between urban and rural trauma care [7]. These inequities have been attributed to a variety of factors including inadequate staffing in rural ER facilities, limited opportunities for continuing medical education, and lack of immediate access to subspecialty care in remote locations [8]. Telementoring and telepresence surgery have the potential to close the gap in trauma care by providing patients and medical staff at community hospitals with immediate access to the expertise of a trauma surgeon and other specialists located at a distant tertiary care facility.

Community surgeons experience a number of challenges as a result of their working environment. They may feel professionally isolated, and unlike their colleagues at larger institutions, they have little opportunity to interact with other surgeons on a day-to-day basis. Opportunities to learn and master new operative techniques are also more limited. For example, the widespread adoption of minimally invasive techniques has been slowed by the inability of the surgical community to meet the training needs of surgeons, particularly those practicing in rural centres. Studies have shown that short courses alone are insufficient to gain proficiency in laparoscopic techniques, leading to higher complication rates for surgeons who attempt a new laparoscopic procedure without any additional proctoring or mentoring [9]. Telementoring can effectively be used to provide surgeons in rural or remote areas with access to the advice and assistance of more experienced surgeons without leaving their local communities [10, 11]. The use of telestration devices, which allow annotation on video images, and robotic arms that allow the mentoring surgeon to control the endoscope are particularly beneficial, as they allow the expert surgeon to take a more active role in the procedure. The use of a multiarmed telemanipulation system allows the expert surgeon to gain true tele-existence, enabling him to perform key steps in a procedure or to take over and complete it if complications arise. Using such a system, novice surgeons can safely progress from observing a new procedure to assisting and eventually to performing it with guidance from the mentor, if required.

In Canada, a telementoring and remote telesurgery network has successfully been implemented, enabling community surgeons in Northern Ontario to safely learn advanced laparoscopic procedures with outcomes similar to those observed in major centres [4, 11]. The establishment of similar telementoring and telepresence surgical networks between teaching centres and rural hospitals could enable community surgeons to offer high-quality surgical care even in the face of rapid changes in techniques and technology. Furthermore, building ongoing collegial relationships between community surgeons and their peers from larger urban centres has the potential to decrease the isolation experienced by surgeons practicing in remote or rural areas.

The ability to offer patients surgical treatment in their own communities benefits not only the patients and the local surgeons but also the healthcare system in general. Countries with large numbers of people living in rural or remote areas frequently struggle to provide them with the same quality of healthcare as those living near urban centres enjoy. The ability to offer a wider range of surgical procedures at community hospitals will help healthcare systems to bridge the gap between regions and offer a more consistent standard of care.

Community hospitals frequently find that they cannot compete with larger centres in times when specialists are in short supply and are also plagued by high physician turnover. Telementoring and telepresence surgical programs provide a mechanism by which community surgeons could keep abreast of the latest developments, avoiding a sense of isolation by building lasting relationships with distant colleagues. This could in turn increase the recruitment and retention rates for community surgeons, helping to break a vicious cycle that leads to chronic understaffing in rural hospitals.

While telehealth initiatives in surgery are in their infancy, programs in other disciplines such as mental health, cardiology, dermatology, ophthalmology are quite well developed [12]. Existing programs utilize real-time videoconferencing for patient assessments and consultations, as well as transmission of ECG data and medical images such as pathology slides, x-rays or MRI scans, either in real-time or by store-and-forward technology. While development of telehealth applications in surgery poses some unique challenges and concerns, the success of current programs in other disciplines is most encouraging.

Technical challenges

Telecommunications issues

Adequate telecommunications networks are of course one of the fundamental requirements for all telemedicine applications. Steady decreases in the cost of telecommunications over the past few decades have led to greater and greater access. However, there are still many areas of the world, particularly in developing nations, with extremely limited and frequently unreliable telecommunications. Even in developed nations, rural and remote areas may have limited connectivity to the Internet and to high-bandwidth modern telecommunications networks.

Videoconferencing and transmission of live surgical field images, which are at the heart of telementoring, have typically used Integrated Services Digital Network (ISDN) technology. ISDN is a digital system that uses circuit-switched technology, in which the two parties are connected via a dedicated circuit, to provide the high speed of transmission and reliability necessary for videoconferencing. Unfortunately, ISDN lines are quite expensive, not widely available outside of metropolitan areas, and completely absent in developing nations. For this reason, Internet technology offers much greater potential for use in telesurgical programs involving rural or remote regions. Its availability is growing rapidly, and the costs are considerably lower. IP networks, in contrast to ISDN, utilize packet-switched technology in which the data stream is broken into packets that are addressed and forwarded along shared lines. While quality of service is a concern with IP (Internet Protocol) networks, virtual private networks can be used to control the amount of packet loss and delay and jitter (variation in packet delay), providing the reliability required for telesurgical applications. Building end-to-end redundancy and diversification into the network creates critical safeguards that minimize the chance of a telecommunications failure during a procedure. In order to provide maximum possible protection to patients against unauthorized access, personal and clinical data and medical images must be encrypted prior to transmission over open communication systems.

Remote telesurgery places an even greater demand on the telecommunications link, requiring low latency in addition to adequate bandwidth and the highest possible levels of privacy, security, and reliability. Network latency is a primary concern during telepresence surgery, since video signals require compression and decompression, which adds significantly to the time required for these signals to make a round trip between the two sites. On the other hand, robotic signals do not require compression and decompression, resulting in increasing discrepancies between the robotic and the video signals as the network latency increases. While studies indicate that surgeons can adapt to latencies of up to 500 ms [13], they cannot adapt to wide fluctuations in latency (jitter) and will experience increased stress and fatigue at longer time delays.

The first demonstration of remote telepresence surgery by Marescaux et al. in 2001 utilized a dedicated connection with asynchronous transfer mode which provided 10 Mbps and an almost constant latency of 155 ms [3]. Unfortunately, such dedicated fiber-optic lines are very expensive and not widely available, even in hospitals in developed countries. In 2002, our group used IP with a virtual private network to conduct a series of 22 remote telepresence surgeries between a teaching hospital and a community hospital over 400 km away in Northern Ontario [4]. In Canada, as in many other countries, these commercially available networks provide a secure link between major teaching centres and most community hospitals and can provide the bandwidth and quality of service required for remote telesurgery.

Wireless communications

Cellular networks have great potential to increase access in traditionally underserviced areas. By eliminating the need for stringing of wire, they offer a relatively low cost of installation and are able to provide service that is adequate for voice communications. However, even the newer generation digital services cannot provide the bandwidth necessary for synchronous telemedicine consults, let alone more sophisticated telesurgical applications [14]. Similarly, satellite systems have the potential to bring connectivity to remote and rural areas. While they can be used for videoconferencing and transmission of medical data, with latencies approaching 1 second, they are not currently used for remote telepresence surgery. While access to telecommunications networks capable of supporting telesurgery in rural and remote areas has severely limited its use to date, future developments in telecommunications technology, particularly in the area of wireless IP communications, will hopefully lead to greatly improved access in the near future.

Robotic platform issues

The development of robotic platforms for medical applications has lagged significantly behind the rapid developments seen in other fields. To date, the Zeus (developed by Computer Motion, Goleta, Calif.) and Da Vinci (developed by Intuitive Surgical, Sunnyvale, Calif.) systems are the only two multiarmed telesurgical systems to receive regulatory approval for telesurgical procedures. However, the Zeus system, in which the robotic arms could be controlled from a remote location via telecommunication link, is no longer commercially available following the 2003 merger of Intuitive Surgical and Computer Motion. Since the Da Vinci system was not designed with this capability, there are currently no commercially available systems that support remote telepresence surgery.

Experience to date with these systems has identified a number of limitations that will need to be addressed if the next generation of robotic surgical platforms is to achieve widespread use [15]. The robotic arms and other components of current systems are quite bulky, creating challenges in the smaller ORs frequently found in community hospitals. Reduced size and greater portability would also be essential if these systems are to be of use for providing emergency surgical care in remote regions or in extreme environments such as spacecraft or battlefields. Their use in such environments will also require that future platforms be more rugged and more easily set up by local personnel.

Since surgical robots will always have to work in very close collaboration with their human operators and with other devices in the OR, future systems will need to be capable of avoiding collision with OR personnel and other equipment, in addition to having some degree of self-awareness. The addition of haptic feedback will also be important to the development of a user-friendly system [16]. With practice, surgeons can use visual cues to compensate for the lack of force feedback on current systems. However, this creates a requirement for extremely high-quality video images and also contributes to surgeon fatigue, especially during longer procedures.

Finally, if new robotic surgical platforms are to find a permanent place in the delivery of healthcare to rural and remote regions, they will have to be far more affordable than their predecessors. Experience to date has shown that in order to be successful, rural telemedicine programs must be financially sustainable after any initial government funding for implementation has run out [12]. The development of versatile systems that can be used for both laparoscopic and open procedures in a variety of subspecialties should help institutions to justify the initial outlay and ongoing expense associated with a robotic surgical system.

Nontechnical challenges

The development of new technology inevitably raises a host of ethical and legal challenges, and telemedicine, including telesurgery, is no exception. In general, there seems to be little middle ground, with most people either enthusiastically supportive or strongly opposed [17]. Concerns over telemedicine programs have ranged from privacy and consent issues and determination of liability amongst the parties involved to the perceived dehumanization of medical treatment. In addition to these issues, telesurgical programs will pose additional concerns due to the capability of the remote surgeon to physically intervene during procedures.

Involving a surgeon from a distant location in the care of a local patient necessitates the transmission of sensitive patient information over public telecommunication networks. Many countries have introduced legislation such as the U.S. Healthcare Information Portability and Protection Act that details the obligations of healthcare providers to ensure confidentiality and security on the patient's behalf. However, the increased sharing of health records between institutions creates the need to develop specific procedures to minimize the risks created by electronic transfer of data and access to this data by a wider range of users. Video recording of consultations, examinations, or surgical procedures also necessitates the creation of policies that deal with the use of such recordings for purposes such as research or quality assurance and audit [17].

The patient consent process is also more complex for procedures involving a remote surgeon. Prospective patients must have a clear understanding not only of the procedure they are undergoing but also of the roles of the remote surgeon and local surgeon or medical team during the procedure and during their perioperative care. They must also appreciate the need to transmit personal information, including medical data via a secure but public network.

A number of unresolved concerns relating to licensing and professional standards will also have to be addressed before remote telepresence surgery can ever become the standard of care in rural or remote areas. Currently, there are no procedures in place in order to facilitate the practice of medicine across geopolitical borders.

However, it is not feasible for an expert surgeon to maintain separate licenses to practice in a large number of locales. It has been proposed that governments could grant licenses by endorsement to surgeons licensed elsewhere or grant legal authority to practice telemedicine in a particular region [12] until a more universal licensing process is developed. At a European workshop on telemedicine held in Strasbourg in 1999, delegates recommended that it would be highly beneficial to develop de facto harmonized codes of practice. These proposed voluntary standards would be a collaborative effort between professional bodies, associations, and other interested parties [18]. In the specific case of telesurgery, it will be necessary to determine the appropriate credentials for using robotic devices to perform remote surgical procedures and also to establish requirements for both mentors and mentees during telementored procedures [19]. It will also be of great importance to develop appropriate validation and assessment tools in order to assess both the cost–benefit ratio of telesurgical programs and their impact on the quality of healthcare provided to patients in rural communities.

Another important issue in remote telesurgery relates to assessment of risk and legal liability. Performing remote surgery entails a number of unique risks, including the possibility of equipment failure or of a loss of communications between the local OR and the remote surgeon. Life-threatening perioperative complications may also arise. Plans must be developed to deal with such occurrences, and the local surgeon must be able to take charge if necessary [20]. These risks will be important factors in defining the limitations of remote telesurgery in rural settings and in determining which types of surgical procedures are the best candidates for integration into telemedicine programs [21]. The use of robot-assisted surgery to enhance surgical care in rural or remote regions will also necessitate a clear understanding of the liability of each party involved. Responsibilities will have to be clearly defined not only for the remote and local surgeons but for the suppliers of the telecommunications equipment and robotic devices used as well.

Finally, issues related to reimbursement of remote surgeons will have to be resolved. These issues will become increasingly complex when programs are developed to provide routine telesurgical care across national borders.

While a number of ethical and legal issues regarding the use of remote telesurgery are yet to be resolved, many of these issues are shared by all telemedicine applications and are gradually being addressed as such programs become more widely used to provide medical care in rural communities. Providing quality care and protecting the rights and privacy of the patient are at the heart of all of these issues. These challenges are not new but have simply become more obvious in the era of telemedicine [17].

Progress to date

Telementoring

During the late 1990s, advances in videoconferencing and improved telecommunications networks led to a number of investigations into the utility of transmitting operative images beyond the OR for educational purposes. Initial studies investigated telementoring from an adjacent room [22] and from a separate building within the same institution [23]. Encouraged by early results showing that operative times and clinical outcomes were similar to those achieved with live instruction, investigators began to evaluate telementoring as a tool for teaching advanced laparoscopic procedures such as colon resections and Nissen fundoplications between more distant sites connected via ISDN lines [10].

In addition to two-way audio and live video, many groups have enhanced the expert surgeon's ability to gain telepresence by remotely controlled robotic devices such as the AESOP camera arm, which allows the remote surgeon to control position of the endoscope by voice commands [23–25]. Several groups have also reported successful telementored urological procedures during which the remote surgeon controlled both the AESOP camera arm and PAKY, a robotic arm for fluoroscopic placement of the needle during percutaneous kidney access [25, 26]. Telementoring configurations may also allow the remote surgeon to control application of electrocautery [27, 28] and may use telestration devices, which allow further enhanced learning experience by allowing surgeons to superimpose notes onto live video images in order to better demonstrate anatomical structures or key steps during telementored procedures [28].

A number of groups have demonstrated the safety and feasibility of telementoring across long distances. Expert surgeons in the United States have telementored advanced laparoscopic procedures in Austria, Italy, Singapore, Thailand, and Brazil [25, 27–30]. While these reports have convincingly demonstrated the utility of international telementoring, all have involved the mentoring of novice surgeons at hospitals in large urban centres. However, it is surgeons practicing in smaller communities far from the nearest teaching hospital who currently have the least opportunity to learn new procedures with the guidance of an experienced mentor.

Rosser et al. [31] successfully used telementoring to enable a surgical resident in a remote region of Ecuador to perform a laparoscopic cholecystectomy with guidance from a surgeon in the United States. The procedure was performed in a mobile surgical unit, using a laptop computer and plain old telephone service to provide two-way audio and video. This mobile surgical program has also used telemedicine for both preoperative evaluation and postoperative care. A laptop computer, digital camera, and access to the internet have enabled the medical team to transmit imaging studies and patient charts, discuss the procedure with the patient from a distant base station, and view images of healing wounds for assessment by a distant expert [32].

Recently, several groups have reported on the successful use of telementoring between large academic centres and community-based centres. Mendez et al. used the Socrates telecollaboration system (Computer Motion) to telementor a series of 6 neurosurgical procedures in Nova Scotia, Canada [33]. Using this system, the remote surgeon was able to control the robotic arm and also view neuronavigational data via ISDN lines which linked the teaching hospital with the community centre 400 km away. According to the local neurosurgeons, the mentor's input was useful in all cases and was essential to the success of two of the procedures.

At the Centre for Minimal Access Surgery in Hamilton (CMAS), Ontario, the Surgical Support Network was established in 2002 to provide surgeons in two rural communities with telementoring support from an expert laparoscopic surgeon practicing at a tertiary care centre in Hamilton [11]. With real-time guidance from the remote surgeon, several community surgeons with minimal experience in laparoscopic surgery have successfully performed laparoscopic Nissen fundoplications, colon resections, splenectomies, and hernia repairs. In a series of 19 advanced laparoscopic procedures completed with telementoring, two anterior resections (total mesorectal excisions) were converted to open when the local surgeon was unable to identify the correct plane of dissection. All cases were completed without intraoperative complications, and postoperative complications requiring reoperation occurred in 2 cases (11%). With the aid of telementoring, the four local surgeons were able to successfully transit from an open approach to a laparoscopic approach without experiencing the high rate of complications frequently reported during the learning curve for laparoscopic procedures.

The CMAS Surgical Support Network utilized two different telecommunications networks: the first being a combination of ISDN and IP and the second being a dedicated IP connection. The greater bandwidth, lower latency, and quality of service provided by the latter was found to offer enhanced image quality and reduced background noise [11]. Although high-bandwidth connections are essential to remote control of the endoscope or other robotic devices, Broderick et al. demonstrated that low-bandwidth connections could successfully be used to transmit video images, provided that camera movements are slowed in order to maintain adequate image clarity and colour fidelity [34]. The ability to utilize low-bandwidth connections will be crucial to the use of surgical telementoring without the use of robotic devices in remote regions and developing nations where access to the latest telecommunications is nonexistent but access to dial-up or wireless internet is available.

To date, evaluations of telementoring and robotic-assisted remote telesurgery have focused on providing surgical care in a hospital setting with a local surgeon and operative team in attendance. However, researchers at the CMAS, in collaboration with NASA, the Canadian Space Agency, and TATRC, the telemedicine research division of the U.S. military, recently demonstrated for the first time the potential to use telementoring to provide emergency surgical care to patients in extreme environments in the absence of a local surgeon.

NASA has conducted a series of NEEMO missions using Aquarius, an underwater research habitat in the Florida Keys, to simulate the confined space and harsh conditions of space travel. During NEEMO 7, nonsurgeon and even nonphysician astronauts aboard Aquarius successfully completed simulated emergency surgical and diagnostic procedures with real-time guidance from experts located in the CMAS telerobotic room in Hamilton, Ontario (Fig. 1). An IP network with virtual private network technology, together with broadband microwave provided two-way audio and visual contact between the two locations. The simulated procedures, performed on artificial cadavers, were chosen to represent medical emergencies that might arise during space flight and included laparoscopic cholecystectomy, arterial anastomosis, ultrasound-guided percutaneous drainage of a cyst, and cystoscopy and removal of a kidney stone. Researchers discovered that real-time telementoring is such a powerful knowledge translation tool that, in an emergency situation, select individuals (such as astronauts) with no medical background can be guided through a lifesaving medical procedure by an expert mentor at a distant location.

Fig. 1. Assisted by a robotic arm, astronaut Bob Thirsk performs a simulated laparoscopic cholecystectomy aboard Aquarius. Dr. Mehran Anvari, who telementored the procedure from Hamilton, Ontario, is visible on the monitor in the lower right corner.

Attempts to use a remotely controlled robotic arm during the NEEMO 7 mission were unsuccessful because the device was too bulky for the very confined space aboard Aquarius. However, with the development of new robotic platforms that are more compact and portable, it is anticipated that remote surgeons will one day be able to combine real-time telementoring with remote telesurgical manipulation to provide emergency medical care in the absence of an on-site surgeon to patients in remote or inaccessible regions on earth or beyond.

Remote telepresence surgery

Although telementoring has been shown to be an effective tool in enabling community surgeons to safely learn new techniques, it provides the expert surgeon with limited opportunities for physical intervention. Even with the ability to control the AESOP camera arm or another single-armed robotic device, the mentor does not have the ability to take over and complete the procedure if complications arise. On the other hand, remote telepresence surgery, using a multiarmed robotic surgical system, enables the surgeon to perform an entire surgical procedure from a location far from the patient.

Jacques Marescaux was the first to demonstrate the feasibility of remote telepresence surgery in September of 2001, when he performed a laparoscopic cholecystectomy on a patient in a hospital in Strasbourg, France, from a surgical console in New York [3]. The procedure was completed without any complications using the Zeus TS robotic system and a dedicated fibre-optic line with asynchronous transfer mode. Until this point in time, robotic surgical systems such as Zeus and Da Vinci (Intuitive Surgical) had been controlled from a console located within the OR or in an adjacent room.

Remote telepresence surgery was used for the first time to perform laparoscopic procedures in a community hospital setting in 2002, when the CMAS established a telesurgical service to provide support to community surgeons in North Bay, a community located over 400 km away from the CMAS facility at a Hamilton, Ontario teaching hospital [4]. The service utilized the Zeus TS telesurgical system and an IP virtual private network that provided 15 Mbps of bandwidth, low latency (140 ms), and a second redundant line as backup. This public telecommunication network links most community hospitals in Canada with tertiary care facilities in urban centres. The remote telesurgical service supplemented the telementoring program already in place between the two hospitals by allowing both the remote and the local surgeon to control the robotic arms and enabling the two to switch roles seamlessly during operative procedures (Fig. 2).

In order to evaluate the feasibility of using remote telesurgery in a community setting, a series of 22 remote laparoscopic procedures, including 7 laparoscopic colon resections, 13 Nissen fundoplications, and 2 hernia repairs were performed between the two institutions [4]. In this series, there were no major intraoperative or postoperative complications and no conversions to open procedures. Use of the robotic system was discontinued during one colon resection due to awkward placement of the robotic arms.

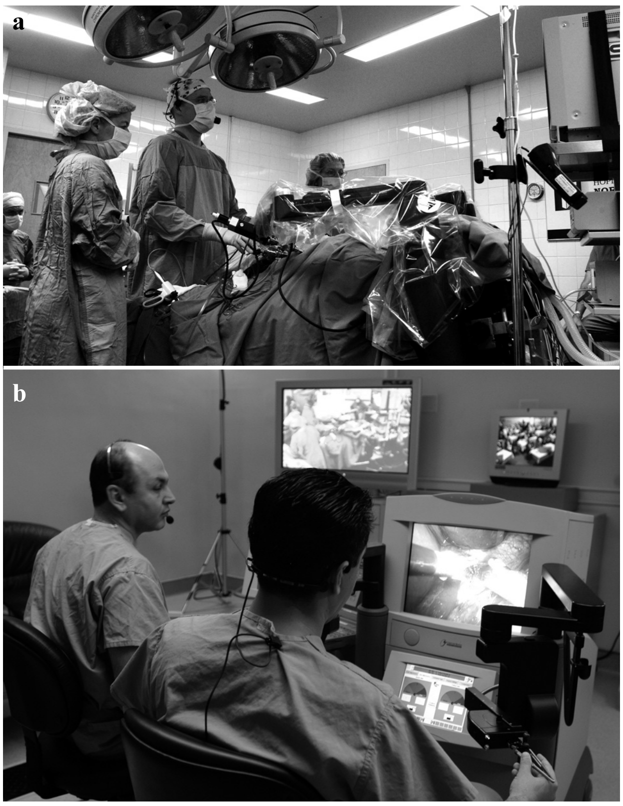

Fig. 2a, b. Remote telepresence surgery between the Centre for Minimal Access Surgery and North Bay District Hospital. **a** The operating room in North Bay showing setup of the robotic arms. **b** The telerobotic room at St. Joseph's Healthcare, Hamilton

The success of this program demonstrates that remote telepresence surgery can provide a safe and effective means to improve the quality and range of advanced surgical procedures offered in a community hospital setting. Furthermore, telepresence surgery can enable community surgeons to adopt new surgical procedures without leaving their local communities and without the high rate of complications frequently experienced during the learning curve for new laparoscopic procedures.

Future developments

Investigations to date have shown that robotic surgical devices and platforms have the potential to enable expert surgeons to gain telepresence in distant communities, and can aid local surgeons in providing improved medical care to patients living far from tertiary care centres. The results of the NEEMO 7 mission suggest that it may even be possible for a distant surgeon to guide a nonsurgeon through emergency medical procedures in very isolated and extreme environments under circumstances where transfer to the patient prior to treatment is not an option.

As robotic technology improves, robotic platforms that are smaller, multifunctional, and more affordable will increase the ability of remote surgeons to share their expertise, benefiting patients in rural communities and the surgeons who practice there. Similarly, advances in telecommunications technology should continue to improve access to telesurgical programs, eventually enabling the development of programs even in remote regions and developing nations where access to surgical care is virtually nonexistent.

Developments in other areas of telemedicine will combine with telesurgery to provide a multidisciplinary approach to healthcare delivery in a rural setting. Applications such as teleradiology, telepathology and real-time teleconsultation are already in routine use, providing improved medical care in many rural communities and remote areas [35–38]. Furthermore, investigations are underway into a number of new robotic applications including a teleoperated ultrasound device [39], a remotely controlled robotic microscope for telepathology [40], and robotic devices for colonoscopy [41, 42].

As discussed, a number of challenges, of both a technical and a medico-legal nature still need to be resolved. In addition, remote telesurgical programs will need to demonstrate their cost-effectiveness and long-term sustainability. However, existing telemedicine programs have convincingly demonstrated their ability to provide improved healthcare for patients in remote and rural communities in a cost-effective manner. Consequently, as telerobotic devices and telecommunications technology continue to improve, telepresence surgery and other interventional telemedicine applications will undoubtedly become increasingly integrated into existing telemedicine programs.

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