Robotic Long-distance Telementoring in Neurosurgery

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OBJECTIVE: To test the feasibility of long-distance telementoring in neurosurgery by providing subspecialized expertise in real time to another neurosurgeon performing a surgical procedure in a remote location**.**

METHODS: A robotic telecollaboration system (Socrates; Computer Motion, Inc., Santa Barbara, CA) capable of controlling the movements of a robotic arm, of handling two-way video, and of audio communication as well as transmission of neuronavigational data from the remote operating room was used for the telementoring procedures. Four integrated services digital network lines with a total speed of transmission of 512 kilobytes per second provided telecommunications between a large academic center (Halifax, Nova Scotia) and a community-based center (Saint John, New Brunswick) located 400 km away.

RESULTS: Long-distance telementoring was used in three craniotomies for brain tumors, a craniotomy for an arteriovenous malformation, a carotid endarterectomy, and a lumbar laminectomy. There were no surgical complications during the procedures, and all patients had uneventful outcomes. The neurosurgeons in the remote location believed that the input from the mentors was useful in all of the cases and was crucial in the removal of a mesial temporal lobe glioma and resection of an occipital arteriovenous malformation.

CONCLUSION: Our initial experience with long-distance robotic-assisted telementoring in six cases indicates that telementoring is feasible, reliable, and safe. Although still in its infancy, telementoring has the potential to improve surgical care, to enhance neurosurgical training, and to have a major impact on the delivery of neurosurgical services throughout the world.

KEY WORDS: Robotics, Surgical training, Telemedicine, Telementoring, Telesurgery

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Advances in computers and telecommunications technology have promoted the rapid development of telemedicine. The electronic transmission of digitized information such as radiological images between distant locations (teleradiology) now is routine in many centers around the world. The development of surgical robotic technology and computerized navigational systems and the establishment of infrastructure for high-speed data transfer have made surgery at a distance (telesurgery) a realistic application of telemedicine in the delivery of surgical care in the future.

Telerobotic systems have made it possible for an expert surgeon in a major health care center to provide real-time guidance to another surgeon in a remote location (telementoring). Telementoring programs have been developed as teaching tools for laparoscopic surgery (2, 20, 23, 27, 31). Furthermore, telementoring networks for laparoscopic procedures linking several remote hospitals with university centers are being established in Japan and Europe (23, 30). Although the initial applications of telementoring have been as teaching approaches to train surgical residents or novice surgeons to perform laparoscopic operations, telementoring applications in other surgical fields have yet to be explored fully.

Neurosurgery is ideally suited for telementoring as a potential teaching tool in neurosurgical training and a means to provide subspecialized expertise in real time to another neurosurgeon performing a surgical procedure in a remote location. Subspecialized tertiary or quaternary neurosurgical services usually are confined to large neurosurgical institutions located in high-density urban areas, whereas centers in smaller urban or rural settings where neurosurgical services are provided may not have the range of subspecialized expertise readily available to larger centers. The assistance in real time (telementoring) of one or more experts from a large center to neurosurgeons in a smaller hospital while they are performing a neurosurgical procedure could be invaluable.

As a part of our institution's robotic neurosurgical program, we started a pilot study of robotic-assisted telementoring between a large academic neurosurgical center (Halifax, NS) and a smaller community-based center (Saint John, NB) located 400 km away. The academic center has a full range of neurosurgical subspecialists in all areas of neurosurgical practice, whereas the community-based center provides general neurosurgical services. This pilot study was designed to test the feasibility of long-distance telementoring in neurosurgery using standard teleconferencing telecommunications technology such as the integrated services digital network (ISDN). We report here our initial experience in robotic-assisted telementoring for neurosurgery.

PATIENTS AND METHODS

Patients

Six neurosurgical patients from Saint John participated in the pilot phase of this study. The patients were fully informed of the telementoring study, and all patients signed an informed consent authorizing the input of the Halifax neurosurgeons during their surgery. The mentors and remote surgeons discussed the cases before the surgery. The patients' charts and all the relevant radiological and laboratory investigations also were reviewed by the mentors before the surgery.

Telecommunications

For telecommunications between the two sites, four ISDN lines were used. Each ISDN line has a transmission speed of 128 kilobytes per second; the total speed of data transmission available for each case was 512 kilobytes per second. The ISDN lines connected the telementoring station located at the robotic mentoring center in Halifax with the neurosurgical operating room in the remote hospital. The four ISDN lines conveyed video data from an endoscope high-resolution video camera held by the robotic arm, video data from two panvision cameras (one camera in each site), neuronavigational data, and two-way audio data. Electronic commands from the mentoring site to control the robotic arm also were sent via the ISDN lines (*Fig. 1*).

Robotic Arm

The robotic arm used to hold the operating field video camera was designed specifically to hold an endoscope. The robot is called AESOP, which stands for Automated Endoscopic System for Optimal Positioning (Computer Motion, Inc., Santa Barbara, CA). AESOP was approved by the United States Food and Drug Administration in 1994 and has been used extensively in robotic-assisted cardiac, abdominal, and urological surgery. The robotic arm attaches to the side of the surgical table and has an adapter system that grasps an endoscope (*Figs. 2* and *3*). The robotic arm is controlled either remotely by the mentor using a telecollaboration system called Socrates (Computer Motion, Inc.) or using voice control by the operating surgeon. AESOP has been found to provide a significantly steadier camera platform than a human camera holder in endoscopic surgery (15).

Telementoring System

The Socrates system is the first robotic telecollaboration device approved by the Food and Drug Administration (13). This robotic telecollaboration system is capable of complex data transmission and allows the control of movements of the robotic arm, AESOP, by the mentor. Socrates also handles two-way video and audio communication as well as transmission of neuronavigational data from the remote operating room. Socrates has an electronic stylus (telestrator) that can be used by the mentor to annotate anatomy or surgical instructions in real-time to the remote surgeon. The telestrator annotations appear in real time on a video monitor depicting the

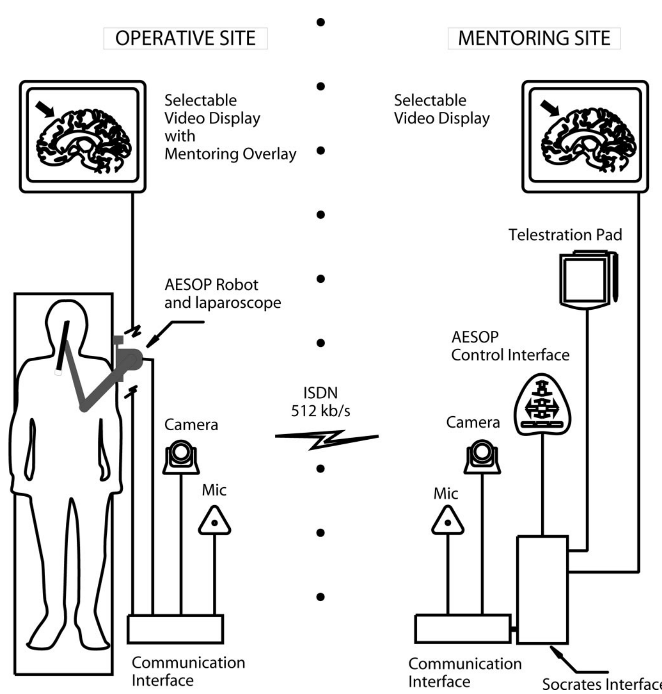

FIGURE 1. *Diagram showing the setup of the different components of the Socrates telecollaboration system (Computer Motion, Inc., Santa Barbara, CA) in the mentoring site (Halifax, NS) and the remote operative site (Saint John, NB) located 400 km away. Four ISDN lines with a total speed of transmission of 512 kilobytes per second provided telecommunications between the two sites.* Mic, *microphone.*

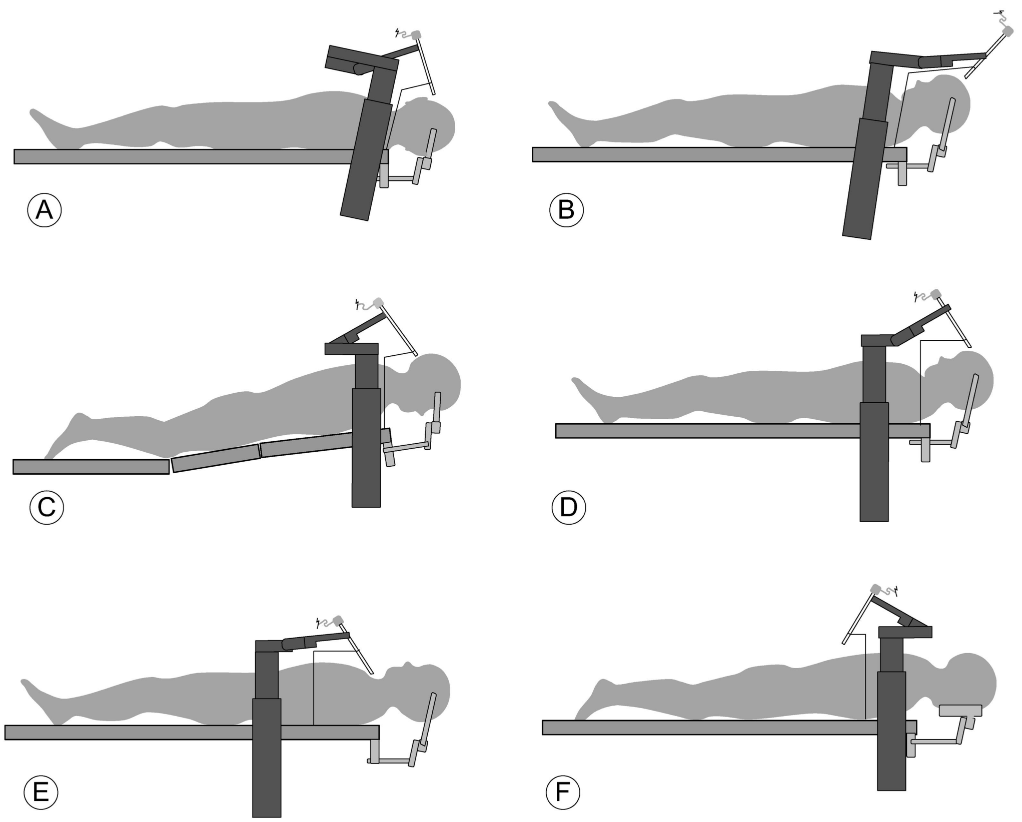

FIGURE 2. *Diagram illustrating the positions of the robotic arm and endoscopic camera in relationship to the patient. The robotic arm is attached to the side railings of the operating table.* A, *position for resection of a temporal lobe tumor.* B, *position for the resection of a parasagittal meningioma.* C, *position for resection of an occipital arteriovenous malformation.* D, *position for a resection of an olfactory groove meningioma.* E, *position for a carotid endarterectomy.* F, *position for a lumbar laminectomy.*

ing of instructions in real time (*Fig. 4*). The mentors had access to real-time neuronavigational data at any time during the surgical procedure.

The mentors also had control of a panvision camera that provided real-time visualization of the remote operating room environment (*Fig. 4A*). The camera could be directed to any area of the remote operating room and allowed visualization of the entire surgical team (neurosurgeons, anesthetists, and nurses) in the remote location. The zoom function of this camera allowed excellent visualization of details such as patient position, surgical instruments on the instrument table, and even radiological films placed on an x-ray light box. Communication between the mentors and the members of the remote surgical team was accomplished quite effectively by the use of two-way video and audio links.

surgical field in the remote site (*Fig. 4A*). The remote surgeons had instant access to the electronic annotations from the mentors at any time during the surgical procedure (*Fig. 4B*).

RESULTS

Long-distance telementoring was used in six neurosurgical cases during the pilot phase of this study. Five subspecialized neurosurgeons in the academic center in Halifax and two general neurosurgeons in the community center in Saint John participated in the telementoring robotic program.

The Mentor Site

The mentors in Halifax had full control of the robotic arm holding the endoscopic video camera and were able to direct the camera, in real time, to any area of interest in the operative field without interfering with any of the actions of the neurosurgeons in the remote location. The mentors were in constant interactive communication with the remote surgeons throughout the procedure. The mentors could annotate anatomy and surgical instructions in the operating field using the Socrates telestrator, which allowed draw-

The Remote Site

The robotic arm AESOP was attached to the operating table in such a manner as to have full access to the operative field and to be unobtrusive to the surgeons performing the operation (*Figs. 2* and *3*). Although the movements of the arm were controlled exclusively by the mentors, the surgeons at the remote location could override the robotic arm movement by voice-activated control. This safety feature was in place in case of interference of the robotic arm with visualization of the surgical field by the electronic commands for the robotic arm by the Halifax mentors. This safety mechanism was never used, because the robotic arm was never in an obstructive position to the surgical field view or any action of the remote surgeons.

The remote surgeons had access to video images that allowed them to see any anatomic or surgical instructions given by the mentors on the surgical field using the Socrates telestrator (*Fig. 4B*). The remote surgeons also had access to two-way video and audio communication with the mentors throughout the procedure.

Patients

Details of the first six patients in the robotic telementoring program are depicted in *Table 1*. All patients expressed their

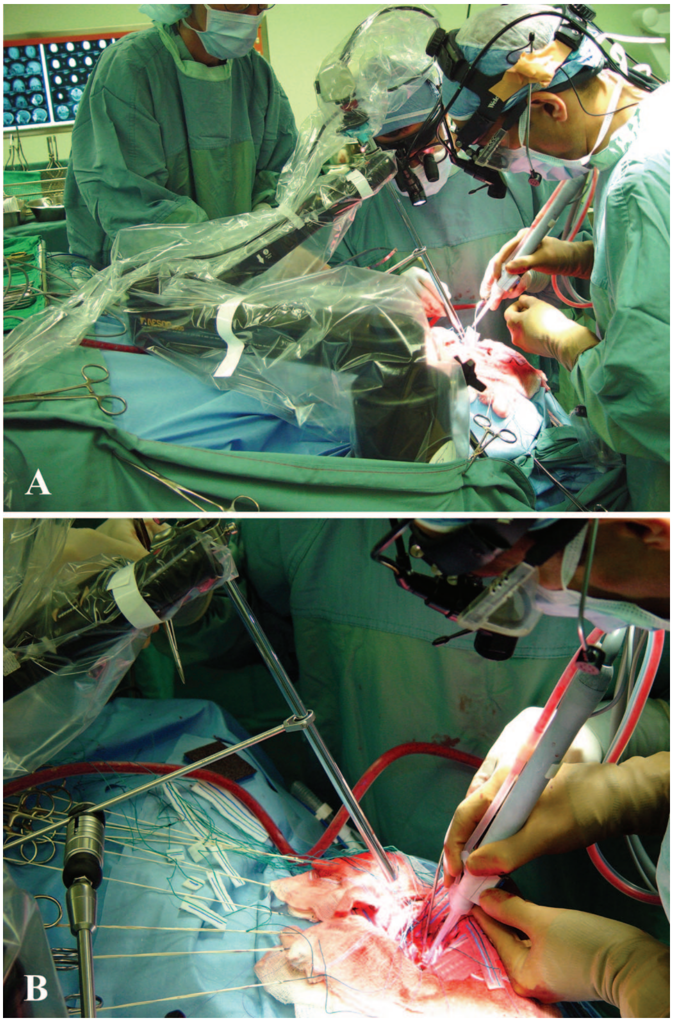

FIGURE 3. A, *photograph of the operating room environment at the remote site showing the position of the operating neurosurgeons and the robotic arm during the surgical procedure. The arm is covered by sterile, transparent drapes.* B, *close-up photograph of the endoscope held by the robotic arm that provides real-time visualization of the surgical field to the mentoring neurosurgeons. The robotic arm movements did not interfere with the actions of the operating neurosurgeons.*

FIGURE 4. A, *photograph of the mentoring site showing the setup of the video screens and panvision camera. The screen on the* left *provides visual input of the remote site operating room environment, whereas the screen on the* right *depicts the surgical field. The mentor on the* right *is using the telestrator pad to annotate anatomy and surgical instructions on the surgical field. Those annotations are transmitted electronically in real time to the remote site.* B, *photograph of the remote site showing one of the operating neurosurgeons consulting the video monitor depicting the surgical field and the electronic annotations from the mentors. There was no perceivable delay on the video and audio feedback from the mentors because it occurred in real time.*

enthusiasm at having "additional" neurosurgeons participating in their operation. Patients believed that there was an "advantage" in having one or more neurosurgeons from a larger center "helping" with their surgery. The surgeons in the remote location believed that the input from the mentors was useful in all of the cases and was crucial in the removal of a mesial temporal lobe glioma and resection of an occipital arteriovenous malformation. The setup of robotic and telecommunications systems in the remote location added approximately 30 minutes to each surgical procedure. However, the remote surgeons believed that this time was compensated for by the useful input from the mentors. There were no surgical complications during the procedures, and all patients had uneventful outcomes.

DISCUSSION

The use of robotic and telecommunications technology has made possible the long-distance interaction in real time of two or more surgeons during a surgical procedure. We used a commercially available robotic-assisted telementoring system to provide neurosurgeons practicing in a community-based hospital with expert advice from subspecialized neurosurgeons practicing in a large academic center. The "presence" of the mentors (telepresence) during the surgical procedures was

TABLE 1. Patient demographics, neurosurgical procedures, and mentoring time[a]

Patient no.	Age (yr)/sex	Diagnosis	Procedure	Mentoring time (h)
1	68/M	Temporal lobe glioma (R)	Craniotomy	3
2	58/M	Parasagittal meningioma (R)	Craniotomy	3
3	38/M	Occipital AVM (R)	Craniotomy	3
4	50/M	Recurrent olfactory groove meningioma	Craniotomy	2
5	63/M	Severe internal carotid stenosis (R)	Endarterectomy	1
6	50/M	Spinal stenosis (L3–L5)	Lumbar laminectomy	1

[a] R, right; AVM, arteriovenous malformation.

considered highly beneficial by the neurosurgeons performing the surgical procedure in the remote location. Although the surgical cases varied in the degree of complexity, the availability of expert opinion in real time provided a sense of a team approach to the surgical procedure. All patients who participated in this pilot program considered it a significant advantage to have input from an expert neurosurgeon during their operation. The interactions between the mentors and the remote surgeons during surgery was efficient and effective to the point that both the mentor and the remote surgeon had a sense that they were in the same room, although they were physically 400 km apart. Although the two sites were connected for the entire duration of the surgical procedure for the first three procedures, it quickly became clear that the input of the mentors was required only during critical aspects of the operation (mentoring time). In subsequent procedures, we became more efficient in the time for connectivity and mentor availability (*Table 1*).

Although the potential benefits of routine robotic-assisted telementoring in neurosurgery have yet to be determined, our experience so far indicates that robotic-assisted telementoring can be conducted effectively in neurosurgical procedures such as craniotomies, lumbar spine surgery, and carotid endarterectomy. We currently are exploring the use of video data from a neurosurgical microscope that may expand the telementoring applications to microneurosurgical procedures. Telementoring in large geographical areas with centralized tertiary and quaternary neurosurgical centers and more abundant community-based neurosurgical services could have important implications in referral patterns and potential benefits for patients and their families by avoiding travel to larger centers and decreasing costs. Telementoring in neurosurgery also could have a major impact on the availability of expert neurosurgeons in the provision of neurosurgical care in centers anywhere in the world where that expertise is not available directly. This could be particularly important in developing countries, where access to neurosurgical expertise is very limited. Teleconsultation using satellite telecommunications to provide neurosurgical consults is already being developed in India (10). The feasibility of long-distance telesurgery has been demonstrated in a transcontinental robotic-assisted laparoscopic cholecystectomy performed between New York, NY, and Strasbourg, France, using a high-speed terrestrial fiberoptic network.

To date, telementoring has been used mainly in endoscopic surgery for gastrointestinal and urological procedures (18, 21, 24, 29). This experience in endoscopic surgery has promoted the development of the "virtual university" concept (23) as a means of providing training, surgical expertise, and dissemination of novel surgical approaches around the world (17, 30). The educational applications of telementoring as a teaching tool for surgical training are yet to be explored. This application will be particularly useful in providing a greater degree of freedom to senior trainees in neurosurgical procedures while the mentor supervises the operation from a station located in an adjacent room. We have started a study using the Socrates telecollaborating system to enhance the surgical independence of senior residents and clinical fellows in our neurosurgical training program.

The applications of surgical robotics are growing rapidly. Advances in robotic-assisted surgery are being made in minimally invasive cardiac, abdominal, and urological surgery. Robotic-assisted coronary bypass grafting and mitral valve replacement are being performed routinely in many centers around the world (6, 8, 14, 25). Robotic gastrointestinal operations such as cholecystectomies (7, 22) and Nissen fundoplications (3, 5) are the most common robotic applications for abdominal surgery. Urologists also have been using robots for endoscopic prostatectomy (1, 26). Robotic applications in neurosurgery mainly directed to stereotactic and endoscopic procedures have been pioneered by innovative neurosurgeons in the past 2 decades (3, 4, 9, 16, 19, 32). More recently, clinical applications of robotic neurosurgical telemanipulation have been reported by several groups (11, 12, 28). Although the practical applications of robotic-assisted procedures in neurosurgery are yet to be demonstrated, as technology continues to advance, robotic applications in surgery are likely to become more prevalent.

In summary, our initial experience with long-distance robotic-assisted telementoring in neurosurgery indicates that telementoring is feasible, reliable, and safe. A number of issues need to be addressed as telementoring and robotic-assisted surgery develop, including medicolegal issues related to surgeon liability and licensing, conflicts of jurisdictions when telementoring or telesurgery is performed between different countries or states, and issues related to remuneration of surgeons and support personnel. Cost effectiveness of robotic-assisted procedures needs to take into account capital investment in robotic systems, initial setup, and telecommunication costs. However, the potential benefits could be enormous, because telementoring and telesurgery have the potential to improve surgical care, to enhance neurosurgical training, and to have a major impact on the delivery of neurosurgical services throughout the world.

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COMMENTS

The authors outline a clinical study in which surgeons in one location were "virtually" assisted by neurosurgeons at a distant site. This was accomplished through live video feedback from a robotically held camera controlled by the "off-location" surgeons. Although this represents an interesting application of high-speed data transmission, the ideas of telepresence and surgical robotics are far beyond the concepts outlined here. The fact that the remote surgeons were able to control the laparoscopic camera is probably of limited practical use in neurosurgery, because the surgical field is much smaller compared with that in the intra-abdominal and intrathoracic procedures it was originally used for. In addition, when a surgical microscope is brought into the field, it seems unlikely that an operating surgeon would relinquish control to an off-site surgeon. Thus, although application of the technology outlined in this paper seems like a long run for a short slide, the overall concepts of telepresent robotic manipulation to serve understaffed or dangerous (e.g., battlefield) locations still remains a worthwhile endeavor.

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The authors have presented an excellent article on what may be a potential teaching tool in the future for training many neurosurgeons in developing countries and for continuing education anywhere in the world. As pointed out by the authors, we should differentiate telementoring from telesurgery. Telesurgery is not new and has been tested in several surgical fields. Unfortunately, at the present time, telesurgery requires very expensive investment and is restricted to highly sophisticated hospitals. It allows an expert surgeon to give orders to the robot from a long distance for the performance of the surgery, but on the site at which the patient is undergoing surgery, a well-trained surgical team always stays ready to act in case of technical problems and is able to conduct the surgery in a traditional manner.

Telementoring, as described by the authors, is very different and should probably be less expensive. Surgery is performed by the local team with the assistance in real time of an expert neurosurgeon who follows the surgery through a high-resolution video camera held by a robotic arm and provides his instructions in real time using the Socrates telestrator. That is obviously an excellent way for practical teaching, avoiding the need for the mentor's traveling, which is time- and money-consuming. We may dream that in the future, some outstanding neurosurgeons would accept a request to telementor to help improve neurosurgery in developing countries. Of course, as ever, the key will be the capital investment in robotic systems and telecommunication costs. As stated by the authors, medicolegal issues should not be forgotten, but they could be solved by official statements between the interested institutions and perhaps the concerned countries. I am deeply interested in following the development of the pioneering work with long-distance robotics-assisted telementoring in neurosurgery initiated by the authors.

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The right cerebral venous system (engraving from De Humani Corporis Fabrica, *1543), by Andreas Vesalius (*from, *Fishman AP, Richards DW:* Circulation of the Blood: Men and Ideas. *New York, Oxford University Press, 1964).*