The Telecommunication Revolution in the Medical Field: Present Applications and Future Perspective

Ravi U. Pande, MD, Yatin Patel, MD,† Colin J. Powers, MD,† Giuseppe D'ancona, MD,‡,§ and Hratch L. Karamanoukian, MD*,†,‡*

*Division of Cardiothoracic Surgery and †Department of Surgery, State University of New York at Buffalo, Buffalo, New York; ‡Center for Less Invasive Cardiac Surgery and Robotic Heart Surgery, Buffalo General Hospital at Kaleida Health, Buffalo, New York; and §The Quebec Heart Institute, Ste Foy, Canada

In the present review, we analyze the achievements of telecommunication innovations in the medical field focusing on patient care and medical-education aspects. In this regard, the telecommunication revolution has offered medical professionals the possibility to transmit information of any sort zeroing transmission time latency and annihilating spatial distances. Although telemedicine is still in its infancy, multiple applications of this science have already been successfully tested. As an example, robotically mediated telesurgery has it made possible for surgeons to operate standing at a considerable distance from the operating table without even touching or directly seeing the surgical field. Moreover, medical education and medical consulting have acquired new and wider ranges of applicability thanks to the introduction of teleproctoring, telementoring, and teleconsulting. Finally, in the very near future, telepresence surgery will permit "virtual" operations on patients where surgeons can project their manual dexterity, psychomotor skills, and problem-solving ability to remote locations. In this context, telemedicine will support a more equal distribution of medical knowledge and promote excellence in patients' care even in the most disadvantaged environments. (Curr Surg 60:636-640. © 2003 by the Association of Program Directors in Surgery.)

INTRODUCTION

Telecommunication: Present Limitations and Future Improvements

Recent developments in the telecommunication field have strongly affected various scientific disciplines, including the medical field. Telecommunications have evolved through years to the point where audiovisual and digital data can be transmitted to and from remote locations all around the globe.[1] For many years, the use of this technology has been a part of telephone consultations performed by medical practitioners. This scant interactivity is sufficient for more simple and conservative management strategies. The current and future prospects of telemedicine demand much more than a rapid exchange of information. This demand can be met by a modality consisting of low latency and high bandwidth, which can transfer large amounts of information at high speed to distant sites.[2] Integrated service digital network (ISDN) and broadband ISDNs (B-ISDNs) based on digital communication are looked on as the solution to this bandwidth problem.[3]

For years, there have been two fundamental types of networks: local area network (LAN) and wide area network (WAN). Today, digital communication is slowly replacing traditional modalities because of its many advantages, such as greater speed and reduced error rates. However, the main disadvantage of these digital modalities is the high cost of service. Because of competition within the telecommunication industry, an increase in service providers and a decrease in cost of service were initially predicted. Unfortunately, over the past couple of years, neither has occurred. In fact, some service providers like "digital subscriber lines" (DSL), which use special conditioners to boost the digital speed of existing copper loops belonging to the local telephone system, have been driven out of business.[2,4] Latency is another problem this technology is expected to face. Presently, except for satellite telecommunications, the remaining modern telecommunication modalities have a low latency.[2] If proper telecommunication modalities of high standards exist in the future, the development of medical telecommunication and telesurgery will depend on its availability in remote rural and underdeveloped areas where it is highly needed.

Telemedicine: Curing at a Distance

The suffix "tele" in the word telemedicine is derived from the ancient Greek and stands for "distance." So telemedicine is the

Correspondence: Inquiries to Hratch L. Karamanoukian, MD, Center for Less Invasive Cardiac Surgery and Robotic Heart Surgery, Kaleida Health at Buffalo General Hospital, 100 High Street, Buffalo, NY 14203; fax: (716) 859-4697; e-mail: lisbon5@yahoo.com

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use of electronic information and communication technology to provide and support health care where distance separates the participants.[5] After making an early start about 40 years ago, telemedicine has progressed slowly until the last decade. The most influential aspect of telemedicine is its ability to provide remote in-home monitoring of elderly patients and patients with chronic diseases. This is important in the clinical care of these individuals, as it provides alternative or equivalent approaches to assess and monitor key indicators of their physical and psychological state. Moreover, remote monitoring is also acceptable to nurses and family caregivers because it is cost effective compared with direct patient care.[4,6] It also has the potential to improve the quality of care by promoting 24-hour critical care services in intensive care units in low-staffed community centers.[4]

Telemedicine has certainly been important for underdeveloped and underserved countries. With the advent of broadband Internet facilities, physicians and surgeons in these developing countries can now turn to their counterparts around the world for advice via teleconferencing. This has the potential to lead to rapid advancements and successful health care delivery systems. Opportunities may also originate for developed countries to learn of the diversity of disease, health care systems, and outcome expectations that exist around the world. Furthermore, developed countries may broaden their knowledge base about infectious diseases, such as HIV and tuberculosis, which are common in developing countries.[7,8]

Telesurgey: From Laparoscopic to Robotically Mediated Procedures

With the introduction of modern robotic technology in the operating room, surgeons are now set to progress in performing remote operations. Although this may seem like science fiction, this technology has evolved into a defined field known as telesurgery. This concept is rapidly gaining popularity with the media and surgical community. Telesurgery can therefore be broadly described as the ability to perform surgery from a distance. The ultimate goal of this nascent field is to perform remote procedures on patients, with modern surgical skills, and overcoming obstacles of time and distance.

The first step toward the realization of this goal was the development of functional and useful laparoscopic instruments. This facilitated the beginning of minimally invasive surgery. The second step was the incorporation of robotic systems in the operating room, with the surgeon being several feet away from the patient.[9] Technically, these robotically assisted procedures can be referred to as telesurgery, where the surgeon physically operates at a distance from the patient and interacts via manipulators.

Surgical Robots: The Actors in the Telesurgery Theater

From industry to operating rooms and now to the operating rooms thousands of miles away, medical robots have indeed come a long way. Early surgical robots were modified industrial robots. They were soon found to be incompatible for use in the operating room as they had many unnecessary features. Modern medical robots overcame these shortcomings by becoming more user-friendly and task specific. Specifically, they were redesigned and reinvented to perform particular tasks with new features compatible with work in the operating room and not the factory. Additional safety features were also added to detect excessive contact pressure or undue proximity by setting limits to the range of motion of the device around patients with specific body geometries (eg, upper and lower limits, etc.). This led to the development of highly advanced robotic systems, which are now US Food and Drug Administration (FDA) approved. Robotic systems presently have two main applications in minimally invasive surgery: first, as assisting devices for solo surgery (image-guided robots) and, second, as robotic manipulators (telemanipulators) for enhanced microsurgical instrumentation.

Today, robotic surgical systems are being used to perform telesurgery in different surgical subspecialties.[10-12] Currently, the most widely available robotic systems in use are the Automated Endoscope System for Optimal Positioning (AESOP) (Computer Motion, Inc, Goleta, California), Da Vinci Surgical Robotic System (Intuitive Surgical, Inc, Mountain View, California), and Zeus Robotic Surgical System (Computer Motion, Inc). Telemanipulators like ZEUS and the Da Vinci are most commonly used robotic surgical systems for telesurgery. Telemanipulators are constantly controlled by an operator who works at an input device, while the operator commands or motions are executed remotely by the manipulator. Unlike the image-guided system where the robot is programmed to perform series of motions, telemanipulators simply respond to instructions. Surgeons manipulate the system from a console, and their gestures are transmitted to the instruments by means of telemanipulation.[13]

The modern medical robotic systems like the Da Vinci Surgical Robotic System and the Zeus Robotic Surgical System have been used successfully to perform telesurgery in both pediatric and adult patients. Although Da Vinci has also been approved by the FDA in 2000 for use in human operating rooms, Zeus is still under trial with limited approval since October 2001.

Teleoperation: Surgery at a Distance

Teleoperation means operating at a distance. The distance between the patient and the surgeon can be minimal while in the same operating room or as far as in two different continents. Regardless of the amount of separation, the surgeon directly controls the motions and contact forces of the remote manipulator in real time. Over the past couple of years, several animal experiments using this service have been reported. Bowersox and Cornum performed nephrectomies, cystotomy closures, and ureteral anastomoses on four anesthetized swines in 1996 using surgical telemanipulators from a distance of 5 m.[14] This was followed by a series of laparoscopic teleoperations in animals, including pyeloplasty, nephrectomy, and adrenalectomy by Sung et al along with a cholecystectomy performed by Marescaux et al.[15-17]

Applications of teleoperation in humans was delayed because of several reasons, such as time lag of existing telecommunication lines, legal and ethical issues, and so on. However, the first intercontinental teleoperation was performed between the United States and Austria on April 8, 1997. A laparoscopic adrenalectomy was performed in Austria while the surgeon steered the robot from Baltimore, Maryland. The laparoscope was maneuvered by an AESOP robotic arm, which was exclusively manipulated from Baltimore via a conventional telephone line.[18]

Marescaux and associates verified the safety and feasibility of teleoperation in humans by performing a laparoscopic cholecystectomy on a 68-year-old woman in Strasbourg, France. The surgeons used high-speed asynchronous transfer mode (ATM) telecommunication technology for the connection between New York and Strasbourg. The ZEUS robotic system manipulated the laparoscope. They described the procedure as safe and successful with minimal time lag and technical difficulties.[19]

Telepresence: The Virtual Surgeon

The most advanced form of telemedicine is telepresence surgery. As the name suggests, telepresence surgery allows the surgeon to perform a "virtual" operation on the patient. Its goal is to provide real-time tactile and visual feedback from the operating site to the surgeon so that the surgeon may then project his or her manual dexterity, psychomotor skills, and problem-solving ability to a remote location.[20] Telepresence surgery can be described as a teleoperation system, where the surgeon directly controls the motion of instruments, but along with sensory input (such as 3-D vision, stereophonic sound, tactile and force feedback) so that an illusion is created of actually being present at a remote site.[3]

Telepresence system was first described and developed by Satava and Green in 1992 as stereoscopic camera, remote manipulators, and stereophonic audio input at the operative site and 3-D monitor, force feedback joysticks, and stereophonic sound system at the workstation.[21] Bowersox and colleagues performed arteriotomy closures on animals using the same system.[22] The first human telesurgical experience was a cholecystectomy procedure done in Belgium using a commercial version of the telepresence surgery system developed by Intuitive Surgical Inc. (Menlo Park, California).[23] There are several other systems currently being developed with similar capabilities in an attempt to reduce the complexity and cost of the system while maintaining a high level of accuracy and safety. Current efforts are being made to provide the capability to perform surgery on the beating heart through motion compensation. This would allow the surgeon to operate on a moving structure with the same precision as if it was perfectly still.

Telesurgical Proctoring, Telementoring, and Teleconsulting: Educating at a Distance

A proctor is a person who provides supervision. The term used in the context of teleproctoring refers to an individual who acts as an observer of a surgical procedure. Teleproctoring is currently used for the purpose of credentialing and granting privileges. Hence, it is essential to specify the precise role of a teleproctor.[24] Teleproctoring can also be used for academic purposes. For example, attending physicians can document and discuss with their residents their individual or team performance during an operation. This may be helpful in establishing a credible credentialing process and thus provides enhanced safeguards to the general public.[25,26]

Telementoring is defined as a remote surgeon acting as a preceptor to provide guidance through difficult operations. Unlike teleproctoring, here the mentor has some ability to control the proceedings that occur at the operating table.[26] Since the last decade, laparoscopic surgery has been rising in demand with an increasing number of surgeons learning and incorporating this technique into their practice. Widespread mentoring and preceptorship is required for this ever-increasing demand to learn laparoscopic techniques. Telementoring may also be useful because it allows surgeons to teach their colleagues without any inconvenience, like traveling to teaching seminars.[24,25] Successful early telementoring experiences have encouraged extensive and wider application.[27]

Rooser et al believe that the concept of telementoring, if properly used, can be a powerful tool for the delivery of health care in underserved communities, along with the safe deployment of advanced surgical procedures worldwide. In an attempt to demonstrate the feasibility of intercontinental telementoring for laparoscopic procedures, Lee et al successfully telementored from the United States a radical nephrectomy and varicocelectomy, which were performed by a less-experienced laparoscopic surgeon in Singapore.[28] Similarly, two laparoscopic cholecystectomies have been telementored between the Johns Hopkins Institute in Baltimore and the National University Hospital in Singapore.[29]

Telementoring a laparoscopic procedure can also be very cost effective and safe during special conditions like war when immediate and expert opinions are required. Cubano and colleagues have successfully accomplished intercontinental laparoscopic telementoring aboard a naval vessel.[30] "Operation Outreach" and "Operation Rainforest" by Rosser and associates are other examples of successful telementoring programs in special conditions. Operation Outreach was one of the earliest advances in telementoring. It was conducted in five different phases with an objective of establishing a telementoring network between the Tripler Army Medical Center in Honululu, Hawaii; the Riverview Hospital in Detroit, Michigan; and the Yale University School of Medicine, New Haven, Connecticut. Operation Rainforest was another project involving Yale University, in which a telementored laparoscopic cholecystectomy was performed in a mobile surgical truck in the middle of the rainforest in Ecuador.[25]

Teleconsultation can be considered a mixture between telementoring and teleproctoring. Although telephone communication may be considered teleconsulting, the use of new communication technology has taken the meaning and application much further. Today, over 250,000 teleconsultations are done annually in various specialties in both military and civilian health delivery systems.[31] Teleconsultation is being used for assisting consultations in dermatology, otolaryngology, radiology, plastic surgery, psychiatry, dentistry, cardiology, pathology, and so on.[32-37]

"Telestroke," is a system developed by Levin and Gorman to provide cerebrovascular specialty consultation to any location within minutes of attempted contact.[38] The University of Massachusetts Memorial Hospital and Beth Israel Deaconess Hospital (Department of plastic surgery) have distinguished themselves in this field and thus deserve special attention. They have designed, developed, and tested a "store-and-forward" system, whereby plastic surgery residents can transmit digital photographs via the Internet to attending physicians on call. This service has proved to be valuable, as high-quality images are sent electronically in minimal time via standard telephone lines.[31]

Telesurgical consultation is a subtype of teleconsultation. It is described as the observation of a surgical procedure by an experienced remote surgeon, who may give advice to the operating surgeon before, during, and after the operation. The surgeon at the primary operating site can also consult colleagues via the teleoperative system at anytime during the surgery.[39] Hence, telementoring and teleconsulting are considered branches of telemedicine.[26,39]

CONCLUSION

The recent introduction and popularization of new information and communication technologies have tremendously increased the velocity of data transmission. These new achievements have already revolutionized the practice in different scientific fields, including medicine. Telemedicine is the direct result of the applied telecommunication revolution. Although this new science is still in its infancy, its applications are growing at a fast pace with very promising results. In this regard, remote robotic telesurgery has proven to be certainly feasible, safe, and useful, especially when performed in specific conditions where a classic surgical approach may not be appropriate. Moreover, teleconsultation, telementoring, and teleproctoring have increasingly been applied to ease patients' treatment at a distance in order to educate, assist, and supervise medical personnel working in disadvantaged environments. Furthermore, remote manipulations have expanded the horizon of mentoring and proctoring in innovative medical fields such as surgical laparoscopy.

We believe the success of technological progress should be measured by the number of people and countries benefiting from it. In this context, telemedicine, and specifically telesurgery, may definitely promote a more homogenous and global distribution of medical and surgery knowledge and grant for excellence in patients' care, even in the most disadvantaged geographic and socioeconomic environments.

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REFERENCES

1. Ziel SE. Telecommunications in health care. *AORN J.* 1998;67:458-459.
2. Feied C. Telecommunications and the next generation internet for health care. *Ann Emerg Med.* 2001;38:293-302.
3. Angelini L, Papaspyropoulos V. "Telesurgery." *Ultrasound Med Biol.* 2000;26:S45-S47.
4. Field MJ, Grigsby J. Telemedicine and remote patient monitoring. *JAMA.* 2002;288:423-425.
5. Field MJ, Grigsby J. Telemedicine and remote patient monitoring. *JAMA.* 2002;288:423-425.
6. Jones JF, Brennan PF. Telehealth interventions to improve clinical nursing of elders. *Annu Rev Nurs Res.* 2002;20: 293-322.
7. Edworthy SM. Telemedicine in developing countries. *Br Med J.* 2001;323:524-525.
8. Lam CLK. Knowledge can flow from developing to developed countries. *Br Med J.* 2000;321:830.
9. Marescaux J, Smith MK, Folscher D, Jamali F, Malassagne B, Leroy J. Telerobotic laparoscopic cholecystectomy: initial clinical experience with 25 patients. *Ann Surg.* 2001; 234:1-7.
10. Bentas W, Wolfram M, Brautigam R, Binder J. Laparoscopic transperitoneal adrenalectomy using a remote-controlled robotic surgical system. *J Endourol.* 2002;16:373-376.
11. Cadiere GB, Himpens J, Vertruyen M, et al. Evaluation of telesurgical (robotic) NISSEN fundoplication. *Surg Endosc.* 2001;5:918-923.
12. Talamini M, Campbell K, Stanfield C. Robotic gastrointestinal surgery: early experience and system description. *J Laparoendosc Adv Surg Tech.* 2002;12:225-232.
13. Donias HW, Karamanoukian RL, Glick PL, Bergsland J, Karamanoukian HL. Survey of resident training in robotic surgery. *Am Surg.* 2002;68:177-181.
14. Bowersox JC, Cornum RL. Remote operative urology us-

ing a surgical telemanipulator system: preliminary observations. *Urology*. 1998;52:17-22.

15. Gill IS, Sung GT, Hsu TH, Meraney AM. Robotic remote laparoscopic nephrectomy and adrenalectomy: the initial experience. *J Urol*. 2000;164:2082-2085.

16. Sung GT, Gill IS, Hsu TH. Robotic-assisted laparoscopic pyeloplasty: a pilot study. *Urology*. 1999;53:1099-1103.

17. Marescaux J, Leroy J, Gagner M, et al. Transatlantic robot-assisted telesurgery. *Nature*. 2001;413:379-380.

18. Janetschek G, Bartsch G, Kavoussi LR. Transcontinental interactive laparoscopic telesurgery between the United States and Europe. *J Urol*. 1998;160:1413.

19. Marescaux J, Leroy J, Rubino F, et al. Transcontinental robot-assisted remote telesurgery: feasibility and potential applications. *Ann Surg*. 2002;235:487-492.

20. Bowersox JC, Shah A, Jensen J, Hill J, Cordts PR, Green PS. Vascular applications of telepresence surgery: initial feasibility studies in swine. *J Vasc Surg*. 1996;23:281-287.

21. Satava RM, Green PS. The next generation: telepresence surgery: current status and implications for endoscopy. *Gastrointest Endosc*. 1992;38:277.

22. Bowersox JC, Shah A, Jensen J, Hill J, Cordts PR, Green PS. Vascular applications of telepresence surgery: initial feasibility studies in swine. *J Vasc Surg*. 1996;23:281-287.

23. Himpens J, Leman G, Cardiere GB. Telesurgical laparoscopic cholecystectomy. *Surg Endosc*. 1998;12:1091.

24. Link RE, Schulam PG, Kavoussi LR. Telesurgery. Remote monitoring and assistance during laparoscopy. *Urol Clin N Am*. 2001;28:177-188.

25. Rosser JC, Gabriel N, Herman B, Murayama M. Telementoring and teleproctoring. *World J Surg*. 2001;25:1438-1448.

26. Docimo SG, Moore RG, Adams J, Ben-Chaim J, Kavoussi LR. Early experience with telerobotic surgery in children. *J Telemed Telecare*. 1996;S1:48-50.

27. Schulam PG, Docimo SG, Saleh W, Breitenbach C, Moore RG, Kavoussi L. Telesurgical mentoring: initial clinical experience. *Surg Endosc*. 1997;11:1001-1005.

28. Lee BR, Png DJ, Liew L, Fabrizio M, Jarrett JW, Kavoussi LR. Laparoscopic telesurgery between the United States and Singapore. *Ann Acad Med Singapore*. 2000;29:665-668.

29. Cheah WK, Lee B, Lenzi JE, Goh PM. Telesurgical laparoscopic cholecystectomy between two countries. *Surg Endosc*. 2000;14:1085.

30. Cubano M, Poulose BK, Talamini MA, et al. Long distance telementoring: a novel tool for laparoscopy aboard the USS Abraham Lincoln. *Surg Endosc*. 1999;13:673-678.

31. Pap SA, Lach E, Upton J. Telemedicine in plastic surgery: e-consult the attending surgeon. *Plast Reconstruct Surg*. 2002;110:452-456.

32. Gilmour E, Campbell SM, Loane MA, et al. Comparison of teleconsultations and face-to-face consultations: preliminary results of a United Kingdom multicentre teledermatology study. *Br J Dermatol*. 1998;139:81-7.

33. Ullah R, Gilliland D, Adams D. Otolaryngology consultations by real-time telemedicine. *Ulster Med J*. 2002;71:26-29.

34. Sorvaniemi M, Santamaki O. Telepsychiatry in emergency consultations. *J Telemed Telecare*. 2002;8:183-184.

35. Scuffham PA, Steed M. An economic evaluation of the Highlands and Islands teledentistry project. *J Telemed Telecare*. 2002;8:165-177.

36. Molinari G, Reboa G, Frascio M, et al. The role of telecardiology in supporting the decision-making process of general practitioners during the management of patients with suspected cardiac events. *J Telemed Telecare*. 2002;8:97-101.

37. Pan CC, Liang WY, Huang CW, Chiang H. Diagnosing minimal adenocarcinoma on prostate needle biopsy by real-time dynamic telepathology through the internet: evaluation of an economic technology for remote consultation. *Human Pathol*. 2002;33:242-246.

38. Levin SR, Gorman M. "Telestroke:" the application of telemedicine for stroke. *Stroke*. 1999;30:464.

39. Cheriff AD, Schulam PG, Docimo SG, Moore RG, Kavoussi LR. Telesurgical consultation. *J Urol*. 1996;56:1391-1393.