Surg Endosc (1999) 13: 673–678

Surgical Endoscopy
Ultrasound and
Interventional Techniques

Long distance telementoring

A novel tool for laparoscopy aboard the *USS Abraham Lincoln*

M. Cubano,[1] B. K. Poulose,[2] M. A. Talamini,[2] R. Stewart,[3] L. E. Antosek,[1] R. Lentz,[1] R. Nibe,[1] M. F. Kutka,[2] M. Mendoza-Sagaon[2]

[1] United States Naval Hospital, 2080 Childs Street, Jacksonville, FL 32214-0324, USA
[2] Department of Surgery, Johns Hopkins University School of Medicine, Blalock 665, 600 N. Wolfe Street, Baltimore, MD 21287, USA
[3] Johns Hopkins University Applied Physics Laboratory, Johns Hopkins Road, Room 13, South 416, Laurel, MD 20723, USA

Received: 31 March 1999/Accepted: 12 January 1999

Abstract
Background: As general surgeons perform a growing number of laparoscopic operations in increasingly specialized environments, the ability to obtain expert advice during procedures becomes more important. Technological advances in video and computer communications are enabling surgeons to procure expertise quickly and efficiently. In this article, we present laparoscopic procedures completed through an intercontinental telementoring system and the first telementored laparoscopic procedures performed aboard a naval vessel.
Methods: Video, voice, and data streams were linked between the *USS Abraham Lincoln* Aircraft Carrier Battlegroup cruising the Pacific Ocean and locations in Maryland and California, creating the Battlegroup Telemedicine (BGTM) system. Three modes of BGTM communication were used: intraship, ship to ship, and ship to shore.
Results: Five laparoscopic inguinal hernia repairs were completed aboard the *Lincoln* under telementoring guidance from land-based surgeons thousands of miles away. In addition, the BGTM system proved invaluable in obtaining timely expertise on a wide variety of surgical and medical problems that would otherwise have required a shore visit.
Conclusions: Successful intercontinental laparoscopic telementoring aboard a naval vessel was accomplished using “off-the-shelf” components. In many instances, the high risk and cost of transporting patients to land-based facilities was averted because of the BGTM system. Also, the relationship between the on-site and telementoring surgeon was critical to the success of this experiment. Long-distance telementoring is an invaluable tool in providing instantly available expertise during laparoscopic procedures.

Key words: Medical Communications — Teleconferencing — Teleconsultation — Telemedicine — Telementoring

Telemedicine refers to the exchange of medically important information among practitioners between local and remote sites. This technology has particular value in surgery by transmitting real-time images, voice, and data across distances, allowing one surgeon to participate at a distance in another surgeon’s procedure [5]. Telementoring, a subset of telemedicine, refers to a more experienced surgeon assisting another surgeon operating at a distance [2]. Such support might range from providing assistance based on a transmitted image to participating actively in the procedure using a remotely operated robot.

Laparoscopy provides an ideal forum for exploring telementoring applications because of the inherent video-based nature of minimally invasive systems. Successful laparoscopic telementoring has been demonstrated over short distances between rooms in the same institution [3]. Telementoring across much greater distances (interstate and intercontinental) offers physicians a valuable tool that would greatly improve patient care by extending expertise instantaneously. However, most patients demand that all of their surgical participants be present in the room at the time of surgical intervention. As such, the clinical need of telementoring systems must be shown and justified. In addition, the logistical hurdles in transmitting real-time video, voice, and data via satellite, until recently, have seemed daunting.

In this study, we examine a long-distance telementoring system composed of readily available components and successfully telementor five laparoscopic procedures. Furthermore, we report the use of this system in a clinically applicable setting: aboard the *USS Abraham Lincoln* Aircraft Carrier Battlegroup (Fig. 1).

Medical and surgical needs in the armed forces repre-

Correspondence to: M. A. Talamini

Fig. 1. *USS Abraham Lincoln* cruising the Western Pacific.

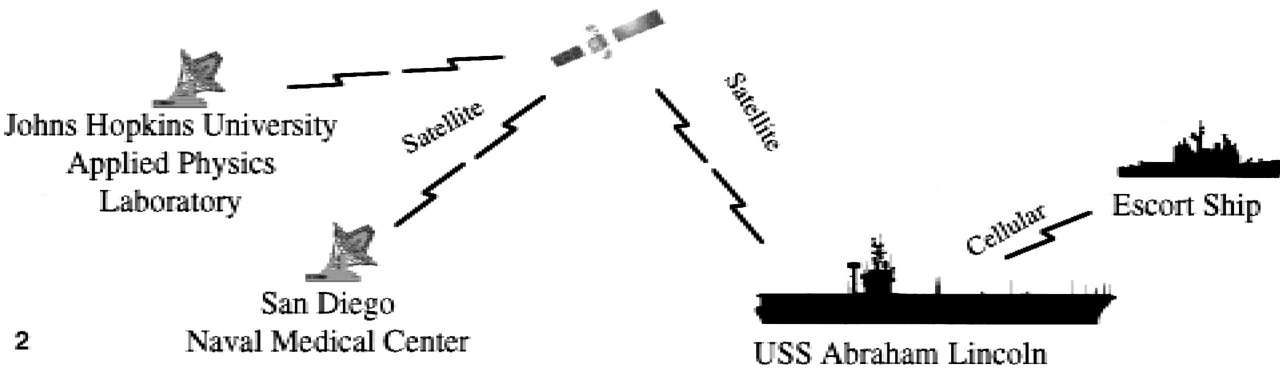


Fig. 2. Battlegroup Telemedicine System. BGTM nodes aboard the *Lincoln* and her escorts are connected by battlegroup cellular telephone. The communications center on board the carrier links voice, video, and data between the *Lincoln*'s Medical Center and sites in Maryland and California.

sent a unique set of consultative needs. This is particularly true with the U.S. naval forces; large battlegroups comprise significant population of personnel in whom surgical intervention at sea often is unavoidable. One surgeon may oversee the care of more than 9,000 people, with even more patients potentially transported to the carrier for evaluation. However, specialization in surgical care has evolved to the point where a single surgeon cannot be maximally trained and equipped in all areas of surgery. The carrier group cannot carry a large enough contingent of surgical specialists on board for all the surgical possibilities that may arise. Therefore, many patients endure helicopter transport over large distances, exposing them to unnecessary risks and incurring great costs. The use of telementoring for operative procedures presents a possible solution to this dilemma. In this article, we describe the hardware–software system, initial testing, performance of laparoscopic procedures, and future plans for a long-distance telementoring system.

Materials and methods

The Battlegroup Telemedicine (BGTM) system, designed by the Johns Hopkins Applied Physics Laboratory (APL), was configured to establish telementoring and teleconsultation capabilities among the *USS Abraham Lincoln* Medical Center in the Pacific Ocean, physicians and surgeons at the APL in Laurel, Maryland, and the San Diego Naval Medical Center (SDNMC). The three communication scenarios explored were intraship, ship-to-ship, and ship-to-shore telementoring. Video, voice, and data streams were linked between computers on the *Lincoln* itself, between the *Lincoln* and its escorts, and among the *Lincoln* and sites in North America, creating the BGTM system (Fig. 2). The BGTM used existing telephone, cellular, and satellite systems to create a low-cost, low-to-medium bandwidth communication system. The central component in BGTM is the VicPhone system (Fiber and Wireless, Torrance, CA) consisting of a video camera, modem, PC-style workstation, and interfacing software. This system provided the ability to transmit the following types of data between BGTM nodes:

- still images (with concurrent voice conferencing)
- image file capture and compression
- motion video (with concurrent voice conferencing)
- digital image highlighting/editing
- electronic data file transfer
- electronic chat
- electronic mail

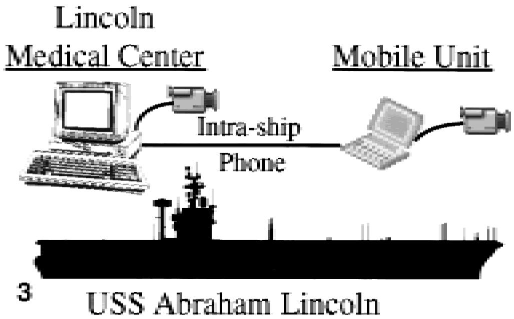
Ships within the battle group were limited to low-bandwidth transmission for general purpose communications, unlike the more commonly used high-bandwidth systems used for land-based telemedicine systems. The minimum expected data transfer rate was 9,600 bits per second (bps), and maximum was 28,800 bps.

Three modes of BGTM communication were employed: intraship, ship-to-ship, and ship-to-shore. Intraship communication took place only on the *Lincoln.* The intraship BGTM system consisted of a mobile unit (laptop computer, modem, video camera, cellular phone) and the *Lincoln*'s Medical Center (Fig. 3). Existing telephone lines also were used for communication between the mobile BGTM unit and the Medical Center. This allowed for transmission of medical data rapidly from a site of injury to the physician staff at the Medical Center.

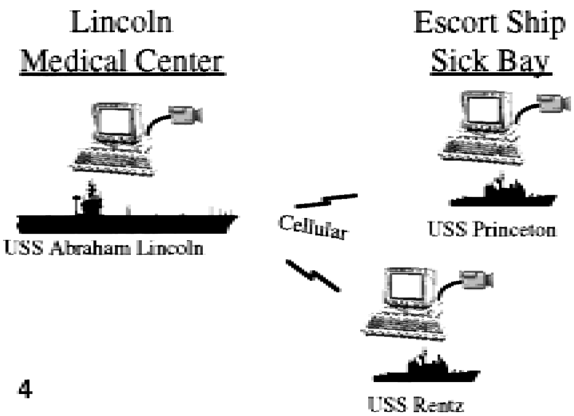
Ship-to-ship transmissions took place via battle group cellular phone link between the *Lincoln* and the sick bays of two escort ships, the *USS Princeton* and the *USS Rentz* (Fig. 4). Thus, corpsmen attending ill service personnel aboard escort ships could interact with physicians aboard the carrier.

Ship-to-shore communication was central to long-distance laparoscopic telementoring. The *Lincoln,* the first Navy ship to be equipped with laparoscopic instrumentation, is capable of performing a wide variety of laparoscopic procedures.

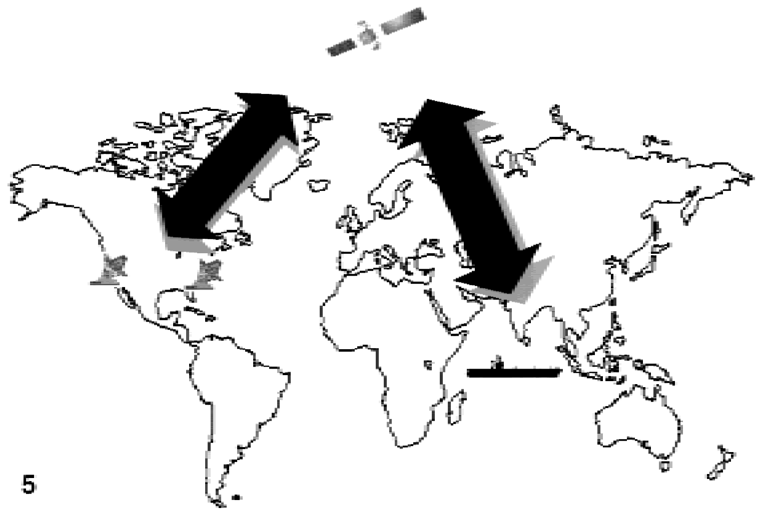
Voice, data, and real-time video images were transmitted using satellite communications, which allowed the VicPhone systems on the *Lincoln* and at the APL and SDNMC to exchange information (Fig. 5). Operating room personnel aboard the *Lincoln* included the primary surgeon, general medical officer, two operating room technicians, and one nurse anesthetist. The operating room was linked directly to the aircraft carrier's communications



3



4



5

Fig. 3. Intraship communications system. Laptop computer with video camera could be transported anywhere within the *Lincoln* and connected directly to her Medical Center, enabling quick physician assessment.

Fig. 4. Ship-to-ship communications system. Patients are brought to the escort ship's sick bay, which is equipped with a desktop computer system and video camera. The sailors' issues are then evaluated by physicians aboard the *Lincoln* through battlegroup cellular link.

Fig. 5. Intercontinental ship-to-shore communications. The *Lincoln* carrier battlegroup on assignment in the Pacific Ocean and Persian Gulf is connected via satellite to North American sites. Physicians on board the *Lincoln* therefore have instant access to medical and surgical expertise for telementoring and teleconsultation, regardless of location during deployment.

center, creating one BGTM node. A second node was created in Laurel, Maryland at the APL. At this site, the experienced laparoscopic surgeon directly telementored the procedures occurring in the Western Pacific Ocean aboard the *Lincoln.* All procedures were performed with a 0° laparoscope and standard laparoscopic equipment (Stryker Endoscopy, Inc., San Jose, CA).

In the young, healthy population of the carrier battle group, symptoms suffered from inguinal hernia represent a common problem requiring surgical intervention that can be managed on board the ship. The benefits and risks of laparoscopic hernia repair were explained to candidate patients, who agreed to undergo the procedure using the BGTM system if they chose laparoscopy.

In all ship-to-shore cases, both the telementoring surgeon and on-site surgeon agreed to identify the following predetermined structures to facilitate completion of each hernia repair: pubic tubercle, bladder, Cooper's ligament, peritoneal lining, transversalis fascia, vas deferens, iliac vein and artery, and the hernial defect. Through digital image highlighting, the telementoring surgeon placed marks on the video screen to identify these structures, and the new "marked" image was transmitted either real time or as a data file to the on-site surgeon, who could use the information to identify these landmarks correctly. In a similar fashion, digital image highlighting was used by the telementoring surgeon to direct stapling of the mesh to cover the hernial defect. Each procedure was deemed complete and successful by both the on-site surgeon and the telementoring surgeon.

Results

Three modes of the BGTM communications system were evaluated: intraship, ship-to-ship, and ship-to-shore. Intraship, real-time information was exchanged successfully between a mobile BGTM unit and the *Lincoln*'s Medical Center using the ship's existing telephone lines. The mobile BGTM unit was tested at various sites around the ship. However, the medical applicability of the intraship BGTM system could not be assessed because of insufficient test opportunities aboard the carrier.

The ship-to-ship BGTM system involved communications between the *Lincoln*'s Medical Center and BGTM nodes aboard two escort ships, the *USS Princeton* and the *USS Rentz.* Real-time video, audio, and data transfer were accomplished at a maximum separation of 28 nautical miles with a sustained information transfer rate of 12,000 bps. This system was used to evaluate and treat definitively traumatic injuries that occurred aboard the escort ships.

One patient received treatment through the ship-to-ship BGTM system. This sailor suffered a traumatic open fracture of the right hand from a gun mount aboard the *Princeton.* Initial evaluation consisted of transmitted voice and images from the escort ship to the surgical staff aboard the *Lincoln.* The injured sailor was transferred from the *Princeton* to the *Lincoln* with the gun mount part impaled in his hand. Aboard the *Lincoln*, radiologic and real-time images were transmitted to the SDNMC, where physicians assisted the ship's surgeon in removing the object. Three days later, the sailor was returned to light duty activity aboard his own ship. Escort ship positioning proved to be an obstacle to successful information exchange. Communications with the *Princeton* were hampered by a cellular phone "blind spot," in which the cellular antenna was blocked by ship struc-

Table 1. Patient characteristics and operative data

Patient	Age	Sex	Laparoscopic operation[a]	Complications
1	23	M	Right inguinal herniorraphy	Postoperative pain resolved with marcaine/xylocaine injection
2	24	M	Left inguinal herniorraphy	None
3	19	M	Right inguinal herniorraphy	None
4	38	M	Right inguinal herniorraphy	None
5	24	M	Left inguinal herniorraphy	None

[a] Operations were performed on board the *USS Abraham Lincoln* cruising the Western Pacific Ocean and the Persian Gulf via telementoring from the Johns Hopkins Applied Physics Laboratory (APL) at Laurel, Maryland, USA

tures. This problem was overcome, however, by proper positioning of the *Princeton* in relation to the *Lincoln.*

Telementoring was used to perform five laparoscopic procedures using ship-to-shore communications between the *Lincoln* and the APL. Five inguinal hernia repairs were successfully completed on board the *Lincoln* by the on-site surgeon under the guidance of a more experienced laparoscopic surgeon (Table 1). The operations on board the carrier were telementored from a BGTM node in Laurel, Maryland—thousands of miles from the operative site.

Case 1

A 23-year-old man presented to the *Lincoln*'s Medical Department with a complaint of pain in the right groin radiating to the right testicle while standing and exercising. This sailor had experienced nonspecific discomfort for more than 1 month, but had denied any inguinal masses. He was evaluated, given a diagnosis of a right-sided indirect inguinal hernia, and prepared for surgery. The technique used to repair the hernia was the transperitoneal onlay mesh repair, in which a prosthetic material was used to cover both the direct and indirect spaces in the extraperitoneal space. The mesh was secured with staples. On postoperative day 1, the patient experienced marked umbilical pain. The workup was negative, and the patient was managed with a local injection of marcaine/xylocaine. He subsequently was discharged and cleared for full duty and full athletic activities thereafter.

Case 2

A 24-year-old man was evaluated at the Medical Department for pain and a mass in the left groin region. The symptoms began 1 month before presentation and progressively worsened, but the man experienced no nausea, vomiting, or change in bowel habits. He was evaluated and diagnosed with a reducible left inguinal hernia. The transperitoneal onlay mesh technique was used to cover both direct and indirect spaces. At the conclusion of the procedure, the sailor was taken to the recovery room, discharged the next day, and soon resumed full activities.

Case 3

A 19-year-old man presented to the Medical Department with right groin pain radiating to the right testicle for the second time in 2 months. Workup revealed a small, right indirect inguinal hernia, which was repaired successfully by transperitoneal onlay mesh placement. The patient recovered quickly and had an uneventful postoperative course.

Case 4

A 38-year-old man complained of a sudden bulge and pain in the right groin after lifting boxes at work. The patient was diagnosed with a right indirect inguinal hernia, which was repaired laparoscopically with a transperitoneal onlay mesh without incident. Postoperatively, the patient experienced mild testicular swelling secondary to insufflation, which resolved without treatment, and the man subsequently returned to work.

Case 5

A 24-year-old man experienced left groin pain for 1 month, becoming worse 1 week before presentation. The patient was diagnosed with a reducible, left inguinal hernia, which was repaired successfully using the transperitoneal onlay mesh technique. He recovered quickly, and promptly returned to full duties.

Real-time video of each surgery was transmitted via satellite at a rate of 2 to 4 frames per second (fps), with data exchange occurring at 9,600 to 21,600 bps. Although video frames were transferred successfully, a 2- to 12-second delay in video exchange was confirmed by voice line. To compensate for the slow rate of video transfer, still frame pictures and voice communications supplemented the video images.

On receipt of a still frame image, the telementoring surgeon placed digital marks on appropriate structures for manipulation, clipping, or suturing. This modified image then was transferred back to the *Lincoln* via data-line transfer, and consultation occurred via e-mail and cellular phone. Occasional delays were experienced in video and still image transfer, although overall image exchange provided adequate vision for successful telementoring.

In addition to telementoring five laparoscopic hernia repairs, the ship-to-shore BGTM system was found to be extremely useful for other clinical needs. Ship-to-shore teleconsultations were employed regarding issues in radiology, dermatology, neurology, and ophthalmology. These teleconsultations occurred between the *Lincoln* and the APL, and also between the *Lincoln* and SDNMC. Furthermore, the BGTM system proved to be a useful tool for improving crew morale. Families were able to communicate face-to-face about newborn infants, medical and emotional problems in the family, and a host of other issues. These "televisitation" opportunities provided a unique and positive way for the sailor to interact with folks back home.

Discussion

In this study, we demonstrate the successful use of a long-distance laparoscopic telementoring system using readily available components. Previous studies have explored telementoring using hard wiring to connect rooms in the same hospital complex, enabling inexperienced laparoscopic surgeons to perform procedures under the guidance of a remote, experienced surgeon [3]. Using similar technology, teleconsulting operations have been accomplished successfully, in which all participants were experienced laparoscopic surgeons [1].

We present procedures accomplished via intercontinental telementoring of a less-experienced laparoscopic surgeon in a particularly useful clinical setting: patient care aboard a United States aircraft carrier. By providing a means to obtain expertise quickly on a wide variety of issues, telementoring provides a critical resource to the primary surgeon aboard the naval vessel via intraship, ship-to-ship, and ship-to-shore modalities.

Although the intraship system could not be tested in a clinical situation, its applicability is evident. Currently, a great deficiency in combat casualty care is the lack of surgical expertise at the time and site of wounding [4]. The ship's surgeon could guide on-site personnel on wound management by directly viewing the particular lesion and providing interventional guidance via real-time video and audio information.

The ship-to-ship BGTM system demonstrated the effectiveness of this concept. The surgeon aboard the *Lincoln* was able quickly to evaluate the sailor who injured his hand in the gun mount aboard the *Princeton.* Appropriate instructions were given via the BGTM system to the corpsman attending the patient, who was then transferred to the *Lincoln*'s medical facilities for complete therapy. Aboard the *Lincoln,* the surgeon was able to send both radiologic and real-time video images of the wound to consultants at the SDNMC. Advice and reassurances from the consulting physicians avoided a costly transfer and week-long hospital stay, reducing the number of man days that would have been lost had the patient been sent to an on-shore medical facility. In addition to providing escort ship personnel with critical on-site information, the surgeon could consult with experts thousands of miles away concerning the management of these acutely injured patients, avoiding costly and unnecessary patient transfers. Ship-to-shore telementoring was used successfully to perform five laparoscopic herniorraphies.

These experiments represent the first use of laparoscopic techniques aboard a combat ship. The procedures were telementored by an experienced laparoscopic surgeon at the APL site while the actual operations were performed by the *Lincoln*'s surgeon in the Pacific Ocean and Persian Gulf. All critical structures were identified clearly by both surgeons. Audio guidance and digitally placed marks by the telementoring surgeon allowed the on-site surgeon's approach to be faster and safer. Although video exchange rates of only 2 to 4 fps were achieved (full motion video rate equals 30 fps), a combination of still image transfer and real-time video provided the most efficient means of updating the laparoscopic surgical field. The satellite voice channels used for ship-to-shore communications at times proved unreliable for sustained support of telementored procedures. Again, this lapse was offset by other means of information exchange: e-mail, data file transfer, and video image transfer.

In short, the different modes of information exchange possible with the BGTM system allowed for continuous communication between surgeons, despite limitations imposed by hardware or software. The VicPhone system in combination with cellular communications provided a low-cost, successful means by which long-distance telementoring of laparoscopic procedures could be accomplished.

Most importantly, this telementoring system provided the opportunity for these patients to be treated on the carrier itself under the guidance of an experienced laparoscopic surgeon, obviating the need for costly transport of patients and personnel to a more specialized environment. Patients experienced minimal pain and returned to work quickly. The benefits of laparoscopic procedures have been treasured in the civilian world. Here, these benefits directly enhanced military readiness.

With an increasing number of women being deployed on naval ships, the BGTM system could prove extremely useful regarding their unique health needs. Because laparoscopy is well established in the gynecologic realm, telementored laparoscopy could provide an invaluable diagnostic and interventional tool used by the ship's surgeon in conjunction with on-shore gynecologic consultants. Currently, many patients with gynecologic issues are transferred to on-shore medical facilities where appropriate treatment can be administered. Not only is a costly transfer and hospital stay incurred, but the significant risk in delaying treatment and the risk inherent to helicopter transport of patients can compromise standard of care. Through telementored laparoscopy, diagnostic and therapeutic maneuvers could be instituted more quickly under the guidance of experienced surgeons while transport and hospital costs are minimized. In this way, standard of care could be maintained as women serve an increasingly critical role in our nation's naval forces.

Although tested in a unique "at-sea" environment, the BGTM system could prove useful in more traditional surgical practice. As mentioned, laparoscopy leads itself well to telementoring because of its video-based nature. With an ever-increasing number of surgeons adding laparoscopy to their repertoire, more-experienced surgeons could be available immediately to assist in procedures performed by their less-experienced counterparts. This may be especially applicable in less urban areas where the patient population could benefit greatly from an increasing array of laparoscopic procedures otherwise unavailable to them.

The success of a telementoring system depends on the hardware–software combination, and most importantly, the relationship between the operating and mentoring surgeons. Currently, hardware and software advances have enabled physicians to gain easy access to the components necessary for a successful telementoring system. Faster computers and routine Internet connections of 28,800 kbps or faster are now commonplace in almost every physician's office. Through these Internet connections, real-time video and voice transfer at 30 fps or faster can now be achieved. In addition, components to create a user-friendly, reliable telementoring system are readily and cheaply available. Here, we demonstrate the current usefulness and practicality of a long-distance telementoring system. With the technology of the near future, such a system would be even more affordable with improved performance.

More important than the mechanical component, the relationship between surgeons is critical to successful telementoring. A functional relationship in which the consulting surgeon recognizes the trained eye of the mentoring surgeon combined with trust in the on-site surgeon's technical capability result in the best possible outcome for the patient.

In concordance with improving technologies, the ability to involve the remote surgeon actively must be explored. Preliminary work suggests that a telerobotic system at the operative site may one day extend the hand of the telementoring surgeon directly onto the surgical field [6]. Extending this idea, robotic force feedback systems could provide the telementoring surgeon a "feel" of the operative site. In this scenario, the telementoring surgeon could directly assist in the procedure with full voice, video, and force-responsive ability to retract and maneuver structures in the operative field. These eventualities would further enhance the usefulness, practicality, and benefit of laparoscopic telementoring.

Long-distance telementoring is a practical means by which patient care can be improved dramatically given the correct setting. We here demonstrate the necessary components inherent to this type of wireless telementoring. With rapid advances in technology, laparoscopic telementoring is proving to be an increasingly affordable and meaningful way of gaining access to expert assistance and improving patient care into the 21st century.

References

1. Cheriff AD, Schulam PG, Docimo SG, Moore RG, Kavoussi LR (1996) Telesurgical consultation. J Urol 156: 1391–1393
2. Kavoussi LR, Moore RG, Partin AW, Bender JS, Zenilman ME, Satava RM (1994) Telerobotic-assisted laparoscopic surgery: initial laboratory and clinical experience. Urology 44: 15–19
3. Moore RG, Adams JB, Partin AW, Docimo SG, Kavoussi LR (1996) Telementoring of laparoscopic procedures. Surg Endosc 10: 107–110
4. Satava R (1995) Virtual reality and telepresence for military medicine. Comput Biol Med 25: 229–236
5. Satava RM, Simon IB (1993) Teleoperation, telerobotics, and telepresence in surgery. Endosc Surg Allied Technol 1: 151–153
6. Taylor RH, Funda J, Eldridge B, Gomory S, Gruben K, LaRose D, Talamini M, Kavoussi L, Anderson J (1995) A telerobotic assistant for laparoscopic surgery. IEEE Engin Med Biol 14: 279–287