JOURNAL OF ENDOUROLOGY
Volume 17, Number 3, April 2003

Is Telesurgery a New Reality? Our Experience with Laparoscopic and Percutaneous Procedures*

PIERLUIGI BOVE, M.D.,[1] DAN STOIANOVICI, Ph.D.,[2] SALVATORE MICALI, M.D.,[1] ALEXANDRU PATRICIU, M.S.,[2] NICOLA GRASSI, Ph.D.,[1] THOMAS W. JARRETT, M.D.,[2] GIUSEPPE VESPASIANI, M.D.,[1] and LOUIS R. KAVOUSSI, M.D.[2]

ABSTRACT

***Background*: Minimally invasive surgery offers many advantages, but its correct practice is associated with a steep learning curve. Telesurgery allows a surgeon at a remote site to guide and teach surgeons at a primary site by utilizing robotic devices, telecommunications, and video technology, thereby reducing complications.**

***Patients and Methods*: From September 1998 to July 2000, 17 procedures were telementored between two sites 9230 km apart: a primary operating room at the Policlinico Casilino "Tor Vergata" University of Rome and a remote site at the Johns Hopkins Medical Institutions in Baltimore. Of these procedures, 14 were laparoscopic cases: 8 spermatic vein ligations, 2 retroperitoneal renal biopsies, 3 simple nephrectomies, and 1 pyeloplasty. Three procedures were carried out to obtain percutaneous renal access. All procedures were performed with the help of two robots: the first robot, AESOP, for the orientation of the laparoscope, and the second one, PAKY, to perform the percutaneous renal access. In addition to the robotic device, the system provided four ISDN lines, a PC with dedicated software to manage the connection, audio and video connections, an external video camera with a panoramic view of the operating room, and remote control of the electrocautery and the Telestrator.**

***Results*: All the procedures were accomplished with an uneventful postoperative course. Ten operative cases were telementored successfully. In five cases, it was not possible to establish a connection to the remote site, and two procedures were converted to open surgery because of intraoperative complications. The time delay of the image transmission was <1 second.**

***Conclusion*: This preliminary experience has demonstrated the feasibility of international telementoring. It could provide education to surgeons and decrease the likelihood of complications attributable to inexperience with new techniques.**

INTRODUCTION

WHAT IS A ROBOT? According to the Robot Institute of USA, a robot is "a programmable multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks." Many systems that can be described as "robotic" are now used in laboratories, and some are undergoing trials in the operating room. Robots designed for surgery have three main advantages over humans. The first is that they have greater three-dimensional spatial accuracy, especially when linked to scanning technology. The second is that the system can be designed to be more reliable and produce more repeatable outcomes. The third is that robots can achieve a precision greater than that achievable by humans.[1]

The utilization of robots in the operating room has been the most challenging application investigated in the health care field. Beginning in the 1980s, the concept that robots were potentially more precise than humans was first investigated in the fields of neurosurgery and orthopedic surgery.[1] These specialties, which focus on surgical procedures performed on organs that provide fixed landmarks as reference points, simplify the

[1]Department of Urology "Tor Vergata" University of Rome, Italy.
[2]Johns Hopkins Medical Institutions, Baltimore, Maryland.
*Presented at the 19th World Congress on Endourology and Shockwave Lithotripsy and 17th Basic Research Symposium, Bangkok, Thailand, November 2001.

task of robot registration and remain at the forefront of surgical robot development. In neurosurgery, three broad types of devices have been developed to improve spatial accuracy and surgical precision: neuronavigators, stereotactic localizers, and robotic assistants.[1–3] In orthopedic surgery, robots that cut or ream bone provide similar advantages.[1] The success of robots in neurosurgery and orthopedic surgery has encouraged the investigation of robots in other surgical specialties, including urology. Within urologic surgery, efforts have been focused on three main applications: transurethral prostatectomy, percutaneous renal access, and general laparoscopic robotic assistance.[7]

The sophistication of present computer and telecommunications technology has provided an exciting new frontier in health care, that is, telemedicine, broadly defined as any medical intervention that uses telecommunication technologies to deliver health care information or services. A potentially powerful application of telemedicine is in teleoperative systems. In this article, we outline our experience with robots in urologic surgery and their role in telesurgery.

PATIENTS AND METHODS

Two separate operative sites were used to perform all surgical procedures. The primary operating room was located at the Policlinico Casilino, "Tor Vergata" University of Rome, while the remote site was at the Johns Hopkins Medical Center, University of Baltimore. The two sites are 9230 km apart.

Primary site

The personnel in the primary operating room included the surgeon, a surgical assistant, a surgical scrub nurse, and a circulating nurse. In addition, for the purpose of the study, an experienced surgeon was in the operating room in case of system failure. This surgeon did not give advice or help to the laparoscopist unless the system could not supply adequate support. If the advice or help of the onsite experienced surgeon was needed, telementoring was considered a failure. The equipment in the primary operating room consisted of standard laparoscopic instruments (Circon/ACMI, Santa Barbara, CA), an external camera system, a multidirectional microphone, and a purpose-built robotic arm to manipulate the laparoscope (AESOP®; Computer Motion, Inc., Goleta, Ca)[5] (Fig. 1B). The external camera was mounted on a movable arm over the operating table and could be coupled by a motor to pan and tilt when controlled from the remote site. After the patient was positioned, the robotic arm was attached to the operating table on which the laparoscope was connected via a magnetic coupling device. This device automatically disconnects from the endoscope when pressure >2 kg is exerted on the endoscope. The robotic arm can be activated by a control pad located at the remote operat-

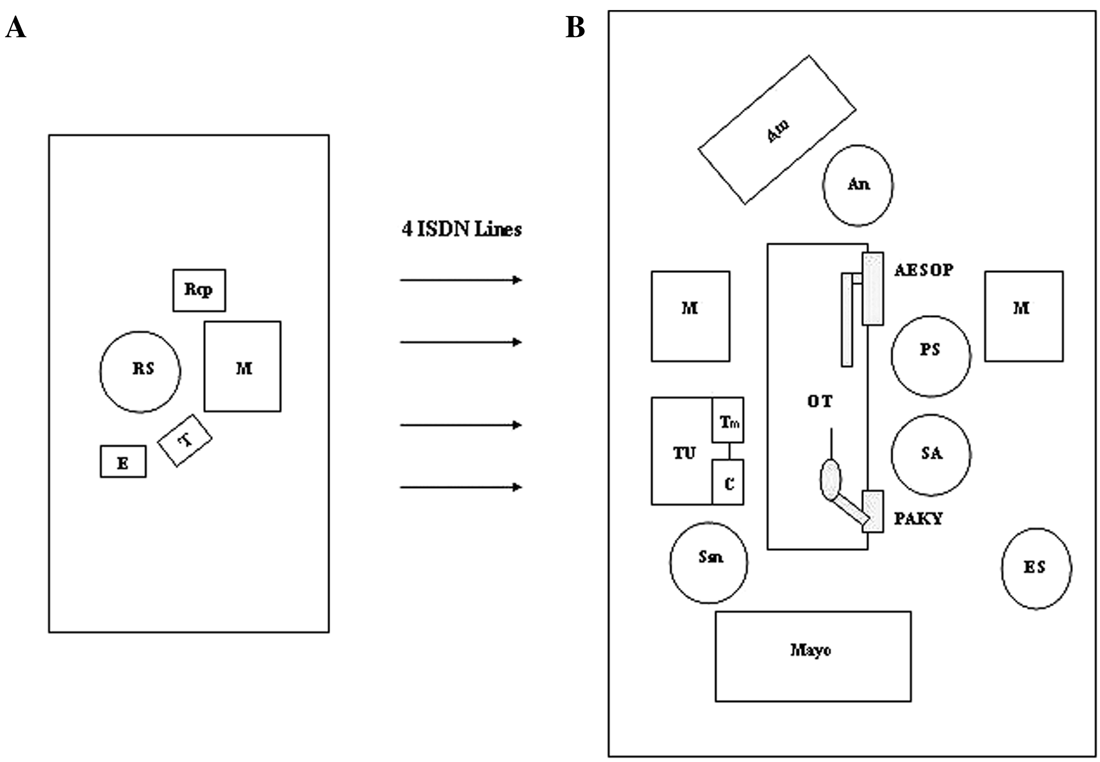

FIG. 1. Room set-ups. (**A**) Remote site. RS = remote surgeon; M = monitor for external and internal operating video images; T = Telestrator; E = electrocautery; Rcp = remote control pad for AESOP and PAKY. (**B**) Primary site. PS = primary surgeon; SA = surgical assistant; ES = experienced surgeon; Ssn = surgical scrub nurse; Mayo = Mayo instrument stand; An = anesthesiologist; Am = anesthesia monitor; OT = operating table with AESOP and PAKY robots; M = monitor; TU = telesurgical unit with Telestrator monitor (TM) and camera (C) for external operating room images.

ing site or overridden by a foot control at the primary operative site. A second robot, PAKY® (***P**ercutaneous **A**ccess to the **K**idne**Y***; Urobotics Laboratory JHMI, Baltimore, MD), was used to perform radiologically guided needle orientation and insertion for the percutaneous procedures. The PAKY mechanical device has a unique needle driver attached to a passive mechanical arm. The device is mounted on a custom-designed rigid siderail, which attaches to the operating room table to provide a sturdy base. Needle insertion is driven by a variable-speed DC motor that is battery powered and controlled with a joystick[6] from either the primary site or remote operating room.

Remote site

The remote operating site was equipped with a high-resolution video monitor with speaker (Triniton MV 9276; Sony Corp., Tokyo, Japan), a multidirectional microphone, a video mixer (digital AV mixer WJ-AVE5; Panasonic, Inc., Secaucus, NJ), a robotic control pad, and a Telestrator video sketchpad (Chryon Corp., Melville, NY) (Fig. 1A). The remote surgeon watched the internal and external views of the primary operating room simultaneously by utilizing a video mixer. The audio and video signals were transmitted to the remote site via high-capacity (ISDN) telephone lines; each line carried 128 kbps. In our case, four ISDN lines were utilized for laparoscopic procedures and three to realize the percutaneous renal access. All the information obtained in the operating room was routed through computers with Pentium 200-MHz processors running software supplied by ICE Communications (Reston, VA). The analog signals generated from each site were converted to digital signals by modem (Fibertek, Inc., Somerset, NJ).

The remote surgeon had the ability to move the AESOP robotic arm holding the laparoscope by means of a control pad, thus directing the operating surgeon to the field of interest. A Telestrator located in the remote room allowed the mentor to draw an overlay image on the video picture generated by the internal camera. This overlay would appear on the image on the internal operating video monitor at the primary operating site. Using this device, anatomic structures and points of interest were directly demonstrated by the monitor. Finally, the electrocautery device was controlled by the mentor for cutting and coagulation functions. By controlling the laparoscope, electrocautery, Telestrator, and audio and video communications, the remote surgeon guided the primary surgeon through the laparoscopic procedures or, alternatively, by using the joystick, obtained complete percutaneous renal access from the remote operating room (Fig. 2).

Operative procedures

From September 1998 to July 2000, 17 procedures were telementored (Table 1): laparoscopic spermatic vein ligation (N = 8) for varicocele, retroperitoneal renal biopsy (N = 2) to determine the cause of chronic renal failure, laparoscopic nephrectomy for a nonfunctional kidney (N = 3), pyeloplasty (N = 1), and percutaneous access to the kidney to perform nephrolithotripsy (N = 2) or position a nephrostomy tube in a patient with an infiltrating bladder tumor (N = 1). Informed consent was obtained from all patients.

Twelve procedures (eight spermatic vein ligation, three nephrectomies, and one pyeloplasty) were conducted with a transperitoneal approach, with the patient in the supine position or, for nephrectomies and pyeloplasty, a modified supine position. During three cases performed by a percutaneous renal approach, the patients were in the prone decubitus position. In the remaining two cases of retroperitoneal renal biopsy, the patients were secured in a standard flank position, and the operating table was flexed to maximize the space of the lumbar triangle (Petit's triangle) between the 12^{th} rib and the iliac crest. A 10-mm incision was made within this area, and a laparoscopic visual trocar, the Visiport® (Auto Suture, US Surgical, Norwalk, CT), was advanced directly into the retroperitoneum under direct vision. This permitted a simple, fast, and safe introduction of the laparoscope.

In all cases, the primary surgeon was less experienced in the laparoscopic technique than the remote one, but he had the basic skills necessary to obtain intraperitoneal or retroperitoneal access. The remote surgeon was experienced with telementored procedures (>30). Sixteen of the seventeen procedures were performed by the same remote and primary surgeons, while in one case, a spermatic vein ligation, the primary surgeon was a

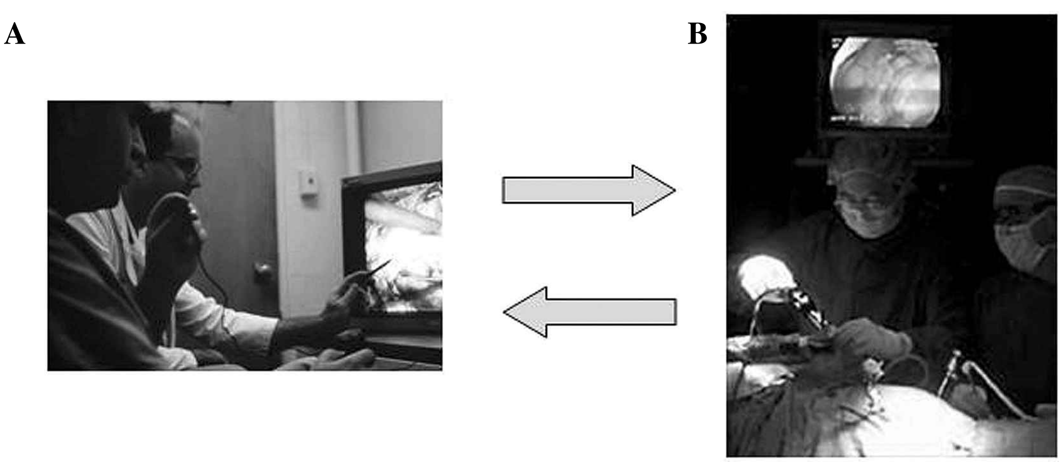

FIG. 2. External view of remote (**A**) and primary (**B**) operative sites.

Table 1. Procedures Performed

Complexity and type	*Number*
Basic	
Spermatic vein ligation	8
Retroperitoneal renal biopsy	2
Percutaneous approach to kidney	3
Advanced	
Nephrectomy	3
Pyeloplasty	1

resident who had laparoscopic experience only with a pelvic trainer.

For the laparoscopic procedures, the operative time was calculated from the first trocar positioning to the closure of all trocar port sites. The operative time for percutaneous renal access procedures was calculated from the first needle insertion to a correct nephrostomy positioning.

RESULTS

All 17 procedures were accomplished with an uneventful postoperative course. Ten operative cases were telementored (performed with the aid of remote operative surgeon through a telesurgical connection). Two procedures were converted to open surgery because of intraoperative complications. In five cases, it was impossible to establish a connection to the remote site, and the procedures were conducted without telementoring in the main operating room (Table 2).

Among the 10 telementored cases, 2 intraoperative technical failures were observed. In one of the two retroperitoneal renal biopsies, the limited space did not permit normal robotic movements and, as a consequence, the laparoscope mounted on the operating table disconnected repeatedly from AESOP. The operation was concluded with the camera controlled by a primary surgeon, thus not influencing the results. The second failure took place during one of the percutaneous accesses to the kidney, where we encountered some problems with PAKY's manual control for needle advancement. The procedure was concluded with the usual manual techniques under remote surgeon teleguidance.

As noted, two procedures were converted to open surgery because of intraoperative complications. During laparoscopic pyeloplasty, the patient developed a severe dysrhythmia, which did not improve after pharmacologic treatment; the pneumoperitoneum was rapidly desufflated, and shortly thereafter, the patient resumed a normal rhythm. The procedure was finished in an open Hynes-Anderson dismembered pyeloplasty. Increased CO_2 absorption was not noted during the dysrhythmia, but CO_2 insufflation at the beginning of the laparoscopic procedure was faster than in the other cases. We supposed this could have been the main cause of the dysrhythmia; the end-tidal CO_2 was normal during the procedure. The second case converted to open surgery started as a laparoscopic nephrectomy, but because several adhesions made adequate isolation of the kidney impossible, the approach was changed in an open radical nephrectomy. The connection with remote sites was successful in both of the converted cases.

The mean estimated blood loss was minimal for all procedures, and no blood transfusion was required except for the converted nephrectomy, which necessitated a 500-mL blood transfusion.

The patient who required manual nephrostomy positioning developed persistent fever. He was discharged home on the seventh postoperative day after proper antibiotic treatment. All operative data are collected in Table 3.

There was a time delay of approximately 700 msec during all procedures, which did not result in any problem with the telementoring program.

DISCUSSION

Preliminary data on the clinical applications of teleoperative systems demonstrate the feasibility of using operative robotic arm to control the laparoscope from an adjacent operating suite.[12,13] Our experiences are an initial attempt to assess the feasibility and utility of clinical telementoring, to resolve surgical training problems, and to improve the performance of more difficult operations in those remote communities where a specialist surgeon is not available.

Following the experience with telementoring and robotic devices at the Johns Hopkins Medical Institutions,[6,7,12,14,15] in 1998, we started a cooperation to study the feasibility of telesurgery between two sites situated more than 9000 km apart.[16] We demonstrated that laparoscopic procedures, even complex ones, and percutaneous access to the kidney can be accomplished by an inexperienced surgeon consulting a remote specialist via a teleoperative system. Our experiences were conducted on 17 urologic cases, and all procedures were successful with uneventful postoperative course.

All laparoscopic procedures were performed using a direct-vision trocar, the Visiport. It allows incision of all tissue layers, thus giving the surgeon complete visual control of the operating field in order to avoid visceral or vascular damage.[17] In 12 of the 14 laparoscopic procedures, we used AESOP, a recently introduced robot that facilitates laparoscopic procedures[20–22]; its use proved to be safe and feasible even when teleguided from Baltimore. An emerging consideration is the importance of anatomic site in the application of robotic de-

Table 2. Telesurgical, Nontelesurgical, and Converted Procedures

Type and procedure	*Number*
Telesurgery (N = 10)	
Spermatic vein ligation	5
Retroperitoneal renal biopsy	2
Percutaneous approach	2
Nephrectomy	1
Nontelesurgery (N = 5)	
Spermatic vein ligation	3
Nephrectomy	1
Percutaneous approach	1
Converted (N = 2)	
Nephrectomy	1
Pyeloplasty	1

TABLE 3. OPERATIVE DATA

Procedure	Mean (range) op. time (min)	Postoperative pain medication requirement	Hospital stay (days)	Return to normal activity (days)
Spermatic vein ligation				
Telementored (N = 5)	39.6 (27.9–51.2)	None	1.8 (0.7–2.8)	6.8 (5.7–7.8)
Nontelementored (N = 3)	28.3 (21.1–35.5)		2.3 (0.8–3.7)	6.0 (3.5–8.4)
Retroperitoneal renal biopsy				
Telementored (N = 2)	36.5 (23–50)	100 mg tramadol	1	3
Percutaneous renal access				
Telementored (N = 2)	12.5	300 mg tramadol	2.5 (2–3)	10
Nontelementored (N = 1)	20	300 mg tramadol	7	15
Nephrectomy				
Telementored (N = 1)	170	90 mg ketorolac	3	7
Nontelementored (N = 1)	200	90 mg ketorolac	3	9
Converted (N = 1)	190	300 mg tramadol	8	20
Pyeloplasty				
Converted (N = 1)	220	300 mg tramadol	8	14

vices. The limited retroperitoneal space is not suitable for proper AESOP movements. Once the primary access is gained, the laparoscope is used bluntly to dissect the retroperitoneal space and mobilize the lateral ***peritoneum*** from the anterior abdominal wall; this usually requires wide laparoscopic movements. AESOP showed no success in performing complex movements against the strong resistance (pressure >2 kg) offered by retroperitoneal tissues.

Unfortunately, we do not have enough cases to make definitive conclusions about PAKY's use in realizing telesurgical percutaneous access to the kidney. However PAKY's ability to assist in percutaneous access to small and delicate renal calices has already been demonstrated.[6,19] In the telesurgical cases treated with PAKY, we noticed better precision of needle advancement into a selected calix, facilitating subsequent percutaneous manipulation. Automated image-guided percutaneous renal access noticeably reduces operators' exposure to X-rays, thus reducing professional risks.

In our experience, telesurgical consultation was successful in 12 of 17 cases, the failures being attributable to the difficulties in linking up with the remote site. Although two procedures were converted to open surgery, the telesurgical connection and the telementoring were correctly realized. In five untelementored cases, it either was impossible to achieve a connection to the remote site or to maintain it. When connecting time coincided with busy American office timetables, several problems arose in maintaining a stable link. In fact, most of the procedures we performed started early in the Italian afternoon (1:00 to 2:00 p.m.), which corresponds to early USA morning hours (7:00 to 8:00 a.m.), when general work activity begins. The loss of connection or the difficulties in establishing it most likely occurred because of international telephone line overload.

Our opinion is that a high-bandwidth telecommunication system is needed to establish a secure connection with the remote site and to transmit operative information in a better way, so that the remote surgeon can evaluate developments in the operative field. Perhaps, in the near future, satellite communication improvements may allow faster and safer long-distance connections and better chances to perform telesurgery with: a digital high-definition television system, excellent security protection using digital encryption, and easy operability.[23,24]

More advanced systems that can actually allow surgical intervention are being tested in laboratory and in clinical and surgical practice. Recently, Reichenspurner and colleagues[9] reported on the use of a voice-controlled and computer-assisted surgical system, ZEUS®, for endoscopic coronary artery bypass grafting. Sung and coworkers[10] have demonstrated the feasibility of a pyeloureteral anastomosis performed completely robotically by the ZEUS system, manipulated from a remote workstation. The most recent generation of robotic devices opens a new era for telesurgery. In fact, once these robots can be used from a remote site, as in telesurgery, the remote surgeon will not only be able to drive or mentor the less-experienced surgeon but also to perform an operation completely by himself or herself. Telesurgery will evolve as a secure method taking advantage of the rapid technological progress and allowing the remote surgeon to have greater interactive capabilities. As in the experience described by Miyake et al[11] with a new television system used in performing experimental ophthalmology surgery. The system not only allowed operations to be performed under lower intensities of operating light but also provided for real-time, highly sensitive 3D images identical to those observed by the surgeon.

Other extremely important aspects are the economic implications of telesurgical consultation and teleoperative systems. At present, commercially available teleoperative systems do not exist. Customized systems are costly, although, as the benefits from these systems became more evident, the cost may be reduced. In addition, fees for the service of the consultant as well as the rental of the telecommunication link need to be negotiated. The transmission cost is approximately 10 US cents/minute for each ISDN line. The cost of PAKY and AESOP is approximately US$80,000 and $30,000, respectively. Formal cost-effectiveness studies will be necessary to assess whether these costs will be offset by the presumed savings attributable to decreased patient and physician travel, as well as potentially better clinical outcomes.[4,18]

CONCLUSION

Robotic surgery and telesurgery allow greater precision in surgical technique, as well as offering the opportunity to provide surgical skill and expertise remotely, even at long distances. The most significant finding is that the application of current communication technology has the potential to completely transform the way in which we perceive the surgical field.

ACKNOWLEDGMENTS

This research was financed by the National Center for Research (C.N.R) of Rome (Italy), which we thank sincerely. Special thanks to Engineer Angelo Lozi, who supported us with great enthusiasm.

REFERENCES

1. Buckingham RA, Buckingham RO. Robots in operating theatres. BMJ 1995;311:1479.
2. Glauser V, Flury P, Burckhardt CW. Mechanical concept of neurosurgical robot "Minerva." Robotica 1993;11:567.
3. Kall B, Kelly P, Stirling S, et al. Computer assisted stereotactic neurosurgery: Functional design, and clinical applications. Proc Int Conf IEE EMBS, Paris, 1992.
4. Perednia DA, Allen A. Telemedicine technology and clinical applications. JAMA 1995;273:483.
5. Sackier J, Wang Y. Robotically assisted laparoscopic surgery: From concept to development. Surg Endosc 1994;8:63.
6. Cadeddu JA, Stoianovici D, Chen RN, et al. Stereotactic mechanical percutaneous renal access. J Endourol 1998;12:121.
7. Cadeddu JA, Stoianovici D, Kavoussi LR. Robotic surgery in urology. Urol Clin North Am 1998;25:75.
8. Satava RM. Robotics, telepresence and virtual reality: A critical analysis of the future of surgery. Minim Invas Ther 1992;1:357.
9. Reichenspurner H, Damiano R, Mack M, et al. Use of the voice-controlled and computer-assisted surgical system ZEUS for endoscopic coronary artery bypass grafting. J Thorac Cardiovasc Surg 1999;118:11.
10. Sung GT, Gill IS, Hsu T. Robotic-assisted laparoscopic pyeloplasty: A pilot study. Urology 1999;53:1099.
11. Miyake K, Ota I, Miyake S, et al. Application of a newly developed highly sensitive camera and 3-dimensional high-definition television system in experimental ophthalmic surgeries. Arch Ophthalmol 1999;117:1623.
12. Kavoussi LR, Moore RG, Partin AW, et al. Telerobotic assisted laparoscopic surgery: Initial laboratory and clinically experience. Urology 1994;44:15.
13. Hurteau R, Begin E, Gagner M. Laparoscopic surgery assisted by a robotic cameraman: Concept and experimental results. IEEE Intern Conf Proc 1994;3:2286.
14. Cheriff AD, Schulam PG, Docimo SG, et al. Telesurgical consultation. J Urol 1996;156:1391.
15. Moore RG, Adams JB, Partin AW, et al. Telementorig of laparoscopic procedures: Initial clinical experience. Surg Endourol 1996; 10:107.
16. Micali S, Virgili G, Vannozzi E, et al. Feasibility of telementoring between Baltimore (USA) and Rome (Italy): The first five cases. J Endourol 2000;14:493.
17. Capelouto CC, Kavoussi LR. Complication of laparoscopic surgery. Urology 1993;42:2.
18. Anonymous. Telemedicine: fad or future? Lancet 1995;345:73.
19. Cadeddu JA, Bzostek A, Schreiner S, et al. A robotic system for percutaneous renal access. J Urol 1997;158:1589.
20. Lee BR, Chow GK, Ratner LE, et al. Laparoscopic live donor nephrectomy: Outcomes equivalent to open surgery. J Endourol 2000; 14:811.
21. Yavuz Y, Ystgaard B, Skogvoll E, et al. A comparative experimental study evaluating the performance of surgical robots AESOP and Endosista. Surg Laparosc Endosc Percutan Tech 2000;10:163.
22. Arezzo A, Ulmer F, Weiss O, et al. Experimental trial on solo surgery for minimally invasive therapy: Comparison of different system in a phantom model. Surg Endosc 2000;14:955.
23. Kiuchi T, Takahashi T. High speed digital circuits for medical communication: The MINCS-UH Project. Methods Inform Med 2000;39:353.
24. Okada Y, Haruhy Y, Ogushi Y. Disaster drills and continuous medical education using satellite-based Internet. Methods Inform Med 2000;39:343.

Address reprint requests to:
Pierluigi Bove, M.D.
Dept. of Urology
"Tor Vergata" University
V. Tiburtina 155
00185 Rome, Italy

E-mail: pierluigi_bove@hotmail.com