Remote Telesurgical Mentoring: Feasibility and Efficacy


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Abstract
We report our experience in performing telesurgically-mentored procedures from Baltimore, MD to Thailand, Austria, Italy and Singapore. We additionally report on a case of remote robotic manipulation using a robot designed for Percutaneous Access of the Kidney (PAKY). Telementoring was performed using a video teleconferencing platform including audio, video, real-time video telestration and remote control of the AESOP robotic arm that manipulates the laparoscopic camera. The international telementoring was achieved over 3- ISDN lines (384 Kilobytes/sec). The robotic arm and PAKY robot were controlled over a separate analog POTS line. Telecommunications links were successfully established to these remote locations that ranged in distance from approximately 4,500-11,000 miles. There was no perceptible impact of time delay on the surgical procedures. All procedures were successfully completed without additional complications. Multiple laparoscopic surgeries to include varicocelectomy (4), nephrectomy (4), adrenalectomy (1) and cholecystectomies (2) were demonstrated. Remote robotic percutaneous access to the kidney was successfully conducted within fifteen minutes from Baltimore, Maryland to Rome, Italy.

1. Introduction

1.1 Telesurgical Mentoring

Recent consolidation and budget cut backs in the medical field has caused a centralization of sub-specialty medical care. Most sub-specialty surgical expertise is concentrated at the large university based medical centers. Less experienced, recently graduated surgeons find themselves in remote locations throughout the world without the benefit of an experienced senior surgeon to continue the clinical proctoring process. This deficit can be bridged with the use of telemedicine to deliver higher quality health care to patients in remote locations. We find that the large medical centers are sometimes the only source for the more advanced medical and surgical care required by certain patients. These centers also serve as the developers of new and innovative minimally invasive surgical techniques that may take years to filter out to the general community. Despite the fact that most surgeons are trained in these advanced techniques during residency, once they matriculate out into the general community the numbers of such difficult cases are to few to keep ones skills sharp. With the recent advances in telemedicine, the experience of the medical center specialists can be projected to these more remote locations by mentoring less experienced surgeons through these complex
procedures. Telesurgical telementoring represents an advanced form of telemedicine, whereby an experienced surgeon can guide and teach practicing surgeons new operative techniques utilizing current video technology, medical robots and high bandwidth telecommunications. This technology can potentially enhance surgeon education, increase patient access to experienced surgeons and decrease the likelihood of complications due to inexperience with new techniques.

The incorporation of video technology into the operating room along with the advances in laparoscopic instrumentation has lead to the development of several new minimally invasive surgical techniques. These approaches are associated with significantly less postoperative discomfort, a more rapid convalescence and minimal disfigurement when compared with traditional open surgical procedures. Unfortunately, many surgeons currently in practice have had little laparoscopic training during their surgical residency. To learn these techniques, current options include training courses, observation and animal labs. However, there is a significant learning curve involved in developing the necessary eye-hand coordination and surgical skill required to perform laparoscopic surgery in a safe and efficient manner. Studies have demonstrated that training courses are insufficient in preparing surgeons to apply new laparoscopic techniques to their patients. In 1993, See et al. reported that surgeons who performed laparoscopy without further training after the initial course of instruction were 3.39 times more likely to have at least one complication than those who sought additional training (1). Hunter et. al. in 1994, attempted to assess the technical ability gained by surgeons after taking a 3-day course in laparoscopic surgery. They reported that although there was improvement by the end of the third day, in general, the steps involved in the more complex procedures were not mastered by the participants (2,3). These data imply that current post-residency training programs are not sufficient in imparting appropriate operative skills to surgeons. Unfortunately, it is impractical for the experienced laparoscopic surgeons to travel and proctor generally trained surgeons each time a new surgical technique is developed. Moreover, it is difficult for surgeons to take time out of their practice each time a new technique is developed.

In an effort to create a safe and effective alternative method of training these less experienced surgeons, a group of physicians and scientists at our institution in 1993 began developing a telerobotic surgical training system. The system is a physician designed, affordable PC-based unit, which uses telecommunication technology to project a surgeon experienced in minimally invasive techniques (specialist) into the operative environment of an inexperienced surgeon (student). The system was designed to be interactive such that a coordinated cooperation between a specialist and student was possible to assure optimal results during the operative procedure. In order to accomplish this, the system was designed to include real time video display from either the laparoscope (internal body view) or an externally mounted camera (overview of the operating room) and full duplex audio communication. To enhance interaction, the specialist is capable of illustrating on the live video image (telestration) and controlling the visual field by manipulating a robotic arm that holds the laparoscope. The system also allows the remote specialist surgeon the ability to activate an attached electrocautery switch to facilitate cutting and cauterization of tissue.

The first telementored consultations using this system have been performed at Johns Hopkins Bayview Medical Center, Baltimore, Maryland using primary and remote operating rooms in separate buildings approximately 1000 feet away (4,5). In this initial testing phase, data was transferred via dedicated hardwired fiberoptic and twisted pair copper wire links which provided dedicated point to point service. Complex laparoscopic cases such as upper pole nephrectomy, gastric augmentation, and bladder augmentation were successfully performed. In the next phase of development and testing, telementored laparoscopic procedures were performed between Johns Hopkins Bayview Medical Center and the main campus at Johns Hopkins Hospital located 3.5 miles away (6). Multiple laparoscopic procedures were performed including cases such as radical nephrectomy, pelvic lymph node dissection, varix ligation and renal biopsy using a dedicated T1 line (1.54 Mb/sec). In both generations of the telementoring system, dedicated telecommunications hardware provided the link between institutions, meaning the systems were hardwired and did not have the flexibility to incorporate additional sites without considerable expense.

To achieve maximum flexibility, the system was augmented with specific hardware to allow the use of the Integrated Services Digital Network (ISDN); a commonly available service offered by regional telephone companies. This upgrade allows dial-up service to any location that has similar ISDN service.
One can use this service over any size communications line from a single ISDN phone line (128Kb/sec) to fiberoptic backbones that can carry over 600Mb/sec. Some experimental systems can now accommodate nearly 3 Gigabits/sec of data transmission. Our current telesurgical mentoring system configuration allows variable bandwidth use over the full range of a T1 line (24 channels, 64Kb/sec per channel). The amount of bandwidth used can simply be chosen via the PC software. An inverse multiplexer (IMUX) allows for more complex configurations of these 24 channels available in the T1 line. Any number of channels up to 24 can be used to transmit data across the system. We typically use a minimum of 384Kb/sec (6 channels) for VTC and 1 channel each for the remote robotic control and the electrocautery switching mechanism. However, to decrease video time delay higher amounts of bandwidth up to 21 channels which corresponds to 1344 Kb/sec of data transmission speed (1-robot, 1- electrocautery, 1-internal control and 21- VTC) is feasible.

1.2 Remote Robotic Percutaneous Renal Access

Minimally invasive surgical procedures have gained popularity and acceptance in recent years because they offer shorter convalescence, better cosmesis and similar efficacy as their more morbid open counterparts. Many of these minimally invasive procedures incorporate a small caliber percutaneous access as the portal of entry. Some of the procedures obtain accurate localization by inserting a small gauge needle into the targeted area for placement of a guide wire. This wire is then used as a guide to pass various dilating instruments over the wire to get a progressively larger tract for placement of a sheath. An example of such a procedure is percutaneous needle access of the kidney. The procedure was first reported in 1976 (7). Since then, with significant improvements in technique, the procedure has become a successful minimally invasive alternative for large kidney stones. Renal access is required for many other urological procedures as well; diagnostic and therapeutic procedures such as the treatment of ureteropelvic junction obstruction, the treatment of upper tract transitional cell carcinoma in select patients and the biopsy of suspicious but otherwise inaccessible lesions in the collecting system. Frequently, the precision of needle insertion has a significant influence on the overall outcome of the procedure. The most common imaging used is a portable x-ray fluoroscopy unit (C-Arm). Due to the complexity of manipulating the needle into three-dimensional space while observing a two-dimensional representation on a monitor, such procedures require extensive surgical training. Even in the most experienced hands percutaneous needle access can be challenging requiring several attempts based on trial and error.

To overcome this problem, the URobotics Laboratory at the Brady Urological Institute, Johns Hopkins University developed a small, portable robotic system that could assist the surgeon with accurate needle placement into the kidney. Previously, the development of a simple, non-computerized system that could be hand carried into the operating room for percutaneous access to the kidney (PAKY) was reported (8). Since this original prototype, a more advanced device was developed using a compact robotic system with a mechanical modular structure. It also was augmented with a global positioning device, a remote center of motion actuator (MINI-RCM) in combination with the radiolucent needle driver, PAKY. With recent advances in telecommunications equipment a remote teleoperated system was also developed called TelePAKY.

We present a case in which the first remote tele robotic percutaneous renal access procedure was performed between the Johns Hopkins Hospital- Dept. of Urology, Baltimore, Maryland, U.S.A. and Tor Vergata University-Dept. of Urology, Rome, Italy over 4,500 miles using a public telephone line.

2. MATERIALS AND METHODS

The remote site was located at the Johns Hopkins Hospital (JHH), Baltimore, Maryland, U.S.A. The local sites were separated from Baltimore, Maryland by approximately 5,000 miles (locations in Innsbruck, Austria and Rome, Italy) or 11,000 miles (locations in Bangkok, Thailand and Singapore). All procedures performed were laparoscopic surgeries with the exception of one remote robotic percutaneous renal access demonstration to Rome Italy.

2.1 Hardware and System Design

2.1.1 Telecommunications Lines

All telementored laparoscopic procedures to the four international sites were conducted over three
ISDN lines producing a data transmission rate of 384 kilobits per second (Kbps). An analog POTS (Plain Old Telephone System) line with a 9600 baud modem was employed to allow communication between the remote site controller and the local site AESOP robotic arm (Computer Motion Inc., Goleta, CA), a second analog POTS line with a 28.8K modem allowed control of the electrocautery.

2.1.2 Core System

A 120-MegaHertz (MHZ) Pentium computer with a video CODEC – CLI Rembrandt 2-VP board comprised the core of the telesurgical workstation. The inputs to the workstation included a wireless Lavalier microphone, video input from the laparoscope, and composite video input from the external room camera. Bi-directional audio, video, camera control and telestration data were available.

2.1.3 Audio / Video Signal

A Pentium processor with a video CODEC – CLI Rembrandt 2-VP board was employed for the videoconference in Innsbruck, Austria and the first iteration in Bangkok, Thailand. The video input was coded under the H.261 video compression-coding standard, which resulted in smooth motion video of 30 frames per second at a resolution of 176 x 144 non-interlaced pixels. The second iteration in Thailand and the International demonstrations in Italy and Singapore used video input that was coded under the H.320 video compression coding standard which resulted in smooth motion video of 30 frames per second and a resolution of 344 x 288 non-interlaced pixels. The audio input to the CODEC boards conformed to established audio standards and resulted in high quality full duplex voice communications.

The data output from the CODEC was fed into a V.35 communications board (Zydacron, Inc., Manchester, NH) which processed and formatted the information to interface with a data switch controller (SLI, Ijamsville, MD). The data switch controller contained a CSU/DSU (Channel Service Unit/Digital Service Unit) which provided the termination for the ISDN line connections (Bell Atlantic) to Johns Hopkins Hospital. The data output from the CODEC was fed to a RS449, which then transferred the data to an inverse multiplexor (IMUX), with NT1 termination. This allowed rapid and reliable data transfer between the local and remote workstations.

2.1.4 Remote Site

The remote site was equipped with a workstation similar to that at the local site. A standard teleconferencing camera (Cannon, Rochester, NY) and microphone were available for routine communications. A pen/pad assembly provided a user-friendly interface for menu selection and telestration. The inputs to the workstation included a balanced microphone, video input from the endoscope, and composite video input from the external room camera.

The custom software allowed the remote physician to control the pan, tilt, zoom, and focus capabilities of the external camera in the operating room. The software had a switch that toggled the video source between the external view and the endoscopic view. The pen/pad assembly allowed the physician to annotate and draw freehand, multi-color figures over the full-motion video screen. These annotations appeared on both the local and remote monitors in well under one second. A software echo cancellation button enabled the audio echo cancellation feature of the CODEC board and resulted in high quality audio.

2.1.5 Automated Endoscopic System for Optimal Positioning (AESOP) robot

A surgical robot (AESOP 1000TS, Computer Motion Inc., Goleta, CA) was available at the local sites for manipulating the endoscopic camera. For the telesurgical system, the remote surgeon was capable of driving the robot via a hand controller located at the remote site. Remote control of the robot was achieved over an analog POTS connection at 9600 baud between local and remote sites. The surgeon at the local site could override the remote control of the robot with the foot control.

2.1.6 Electrocautery

Control of the Electrocautery Force 2 Generator (Valleylab Inc., Boulder, CO) was achieved with a PC switch connected to a 28.8K modem interfaced to the remote unit over a second analog POTS line. Termination of the connection was established with a second modem in the operating room, which connected to the electrocautery unit.
2.2 PAKY Robot

This device includes two components: the PAKY (Percutaneous Access of the Kidney) needle driver and the RCM (Remote Center of Motion) robot:

FIGURE 1. Schematic of the PAKY robot which includes two parts:

a.) RCM (Remote Center of Motion) robot
b.) PAKY (Percutaneous Access of the Kidney) needle driver.

2.2.1 PAKY (Percutaneous Access of the Kidney) Needle Driver

This component is a radiolucent mechanical needle driver used to position and actively drive an 18 gauge percutaneous access needle into the targeted tissue or organ. Since the needle driver is radiolucent it allows unobstructed visualization of the target organ and fluoroscopic guidance of the needle (9). An electric motor performs the automated needle insertion after the RCM robot accurately positions the needle along a predetermined path. The driver is a patented device based on a novel mechanical transmission principle that allows accurate axial loading of forces. The disposable driver is constructed of an inexpensive acrylic plastic, which is easily reproduced and can be sterilized. The PAKY needle driver has been successfully used for several clinical cases (8,10).

2.2.2 RCM robot (Remote Center of Motion)

This component is a relatively small robot used for percutaneous surgical applications that use a fulcrum point for location, such as a needle placed against the skin. This robot is a compact design: it may be folded into a 171 x 69 x 52-mm box and it weighs only 1.6 Kg. The robot precisely orients an end-effector (i.e. surgical instrument) in space while maintaining a fixed location at the level of the skin. In this application, we use the RCM in conjunction with the PAKY needle driver for performing image guided renal access. This combined device can be mounted directly on the operating room (OR) table by using a passive positioning arm that can be locked in place after adequate orientation and skin placement of the needle tip is obtained (Figure 1). The robot orients the needle in the correct path after the desired end point is determined (e.g. calyx of the kidney or stone) using X-ray fluoroscopy guidance from a C-Arm imager controlled by the surgeon. The path is automatically calculated using the fixed point at the skin and the end point in the targeted organ, once activated the needle driver inserts the needle tip to the desired location. The PAKY robot has been successfully used at the Johns Hopkins Medical Institutions for nine surgical procedures (11,12). Additional information on the PAKY needle driver and RCM robot components is available at the following URL’s: http://prostate.urol.jhu.edu/research/urobotics/projects/paky/index.html, http://prostate.urol.jhu.edu/research/urobotics/projects/rcm/index.html

2.2.3 Telecommunications Equipment for PAKY Robot

Control of the robot’s movements was established over a plain old telephone system (POTS) line in a serial communication protocol using custom software developed using Visual C++, Motion Engineering Control Libraries, and GreenLeaf Com++. The user interface of the control program displays three bi-directional arrow buttons which control the direction of movement for each motor of the robot: two for needle orientation and one for needle insertion. A first set of controls is located on the local PC. For teleoperation a second set of arrow controls with identical functionality is displayed on the remote PC, such that the robot can be controlled from either location. This double control scheme was selected for remote to local teaching purposes. Remote control is implemented on a second PC. Both PC’s are equipped with internal modems.

Menu based software commands integrated with an IEEE interface; a PCX/DSP motion controller card to the robot (Motion Engineering Inc, Santa Barbara, CA) allowed control of movement along each axis via...
a mouse interface. The robot is equipped with three Maxon electrical motors with optical encoders.

Local override control of the needle’s position was possible via a joystick interface. As well, termination of the procedure was possible through local override of the commands, termination of the software program, termination of power to the robot or termination of the communications link. A telesurgical software platform (ICE Communications, Reston, VA) allowed remote control of external camera views through which the remote surgeon could observe movement of the robot and visualization of the fluoroscopic x-rays. A multidirectional microphone conveyed full duplex audio between local and remote sites. As well, the ability to telestrate on the computer screen allowed the remote surgeon to identify anatomical structures.

After first defining the skin insertion site and the anatomical target calyx, the RCM (Remote Center of Motion) robot is remotely positioned to precisely orient the needle such that alignment of the needle, skin insertion site and target calyx is obtained under fluoroscopy. This position is held so that the correct needle axis is maintained during advancement.

2.3 PAKY Clinical Data

The patient was a 73-year-old male who had undergone previous radical cystoprostatectomy for transitional cell carcinoma. He had cutaneous ureterostomies performed to divert his urinary contents and over a prolonged period of time developed progressively severe left-sided hydronephrosis with parenchymal thinning on ultrasound consistent with chronic obstruction. His creatinine was 1.2 mg/dl (normal). The patient was positioned prone on the operating room table in Rome, Italy and pre-operative antibiotics were administered. The combined PAKY robot (PAKY needle driver + RCM robot) was mounted directly on the operating room table, covered with a sterile drape after adequate skin preparation. A telephone connection was established from Baltimore, Maryland, USA. The PACKY robot was manually positioned such that the needle tip was located at an appropriate skin entry site that would produce a suitable tract for placement of the endoscopic instrumentation. The C-Arm was manually positioned over the patient and the x-ray image was transferred to the telesurgical systems computer. On the computer monitor, the surgeon specified the desired end point for the tip of the needle by pointing at it with a mouse. An oblique view was acquired by rotating the C-Arm unit. In the oblique view, the surgeon again localized the end point desired. Using triangulation the computer automatically orients the robot and needle such that it points to the specified target. Needle insertion was controlled and monitored by the surgeon while observing the real-time oblique fluoroscopic view. Using the telesurgical system, Dr. Louis R. Kavoussi, Professor of Urology, Johns Hopkins Bayview Medical Center in Baltimore, Maryland, USA remotely controlled positioning and the advancement of the needle in Rome, Italy.

3. RESULTS

3.1 Telesurgical Mentoring Cases

International telesurgical mentoring over a variable distance of 4,500-11,000 miles was successfully conducted for the Thailand and Austrian experience. Each laparoscopic procedure (varicocelectomy, adrenalectomy, and nephrectomy) was completed without intraoperative complications. Perioperative parameters such as estimated blood loss and operative times were similar to the expected non-mentored procedures. Additional cases were completed in Rome, Italy (1-varicocelectomy, 2-nephrectomies) and Singapore (2-varicocelectomies, 1-nephrectomy, 2-cholecystectomies). These cases were also completed without complications or communications malfunctions.

The average time delay for the international procedures was less than 500 msec. This delay includes transmitting the robotic movement signal from the remote location to the local site and the reflection of the video signal back to the remote site. The estimated time delay for a one way signal to Europe was approximately 140 msec and to the Far East was approximately 250 msec. This brief time delay was not a detriment to robot movement.

3.2 Remote PAKY Robot Case

To gain renal access, the mechanical arm was remotely manipulated over two axes of movement to align the needle over the skin entry point and along the trajectory line between this skin entry point and the targeted calyx. The C-arm fluoroscopy unit was then manually rotated 30 degrees and the percutaneous needle was then remotely advanced from the United States, 4,500 miles away. Once the needle tip was seen within the calyx, successful placement was confirmed in the traditional fashion (drainage of urine through the needle and passage of a
wire into the collecting system). Once access was secure, the needle was backed out over the wire by the surgeon in the local operating room and the entire device was moved aside. A 16F nephrostomy tube and an 8F ureteral stent were left in place after the procedure.

This new telesurgical robot was successful at obtaining percutaneous access within 20 minutes, with two attempts to obtain entry into the collecting system. On the first attempt, malpositioning of the robot prevented adequate needle placement. On the second attempt, the robot was positioned more cephalad to decrease the tract length of the percutaneous needle.

4. DISCUSSION

4.1 Telesurgical Mentoring

Our experience with telementoring has evolved from using the network within the same institution, to a multi-institution point to point configuration, to its present international capability with dial-up ISDN service. In its current form, the telementoring system utilizes an inverse multiplexer, which offers switched telecommunications service, thereby allowing more flexible application of the system. In this configuration, commercially available phone lines suffice, without the need for additional lines or dedicated point to point service. Using switched access service means that different institutions can dial into a video conferencing system using public telephone lines if the correct format is used. In fact, with current commercially available video bridge technology multiple institutions at different remote locations could patch into the primary link as observers. Peripheral technology has been added to the system such as a retractable arm for overhead cameras and a head mounted video display system, both of which allow the telesurgical system additional flexibility for use in open surgical procedures as well as the current laparoscopic application.

Telesurgical telementoring produces an interactive surgical mentoring experience, which is made possible only with recent advances of digital telecommunication technology. In order to transport the operating room environment to the mentor, data needs to be translated into digital format, transmitted between institutions, then displayed in a user-friendly fashion. As the distance expands between the two endpoints of local and remote operating rooms, the delay in signal transmission between points will become more apparent. Time delay is not only a function of distance, but also of hardware and bandwidth. There is a defined internal delay in each telesurgical system. The signal originates with an analog camera, which is converted into a digital format. This signal is sent to the CODEC, where it is coded and compressed, then sent to the IMUX which relays the digital information over the telecommunications line. A second IMUX on the receiving end will obtain the signal, pass it to a second CODEC located in the remote computer where the signal is decoded, uncompressed, and formatted for viewing on a computer monitor. Increased bandwidth will improve transmission time; however, there is an inherent delay in the speed that the CODEC can process the signal. As the cost of bandwidth access decreases, and its availability increases, adding more bandwidth to the application could shorten the time delay. Additional time delay decrease will eventually be realized when faster and more efficient loss-less video compression is developed. In fact, as computer processors and CODEC compression become quicker these links could be made via laptops over the internet.

We incorporated the AESOP robot into the telesurgical mentoring system so that the mentoring surgeon could manipulate the laparoscope and camera from a remote location. As a safeguard, the local surgeon has the ability to override remote robotic control. A third technological advance incorporated into this system was the ability to control the electrocautery from a remote location. Custom software was developed that allowed cutting of tissue and cauterization of bleeding blood vessels during surgery by the remote surgeon. The laparoscopic nephrectomy performed in Bangkok, Thailand represents the first time remote control of an electrocautery device was achieved at extremely long distances (~11,000 miles).

Our target audience comprises practicing surgeons who desire improved competence in minimally invasive techniques. As well, this system may improve the delivery of health care to patients by providing more experienced supervision during complex surgical procedures. The success of this system has induced collaboration with many institutions that may one day evolve into a telesurgical network spanning the globe. Our system is the first generation; it is PC-based, affordable and utilizes public communication links. The next step is to familiarize patients and surgeons with this technology and to encourage its application. In the future, when a high bandwidth solution becomes available to the Internet these types of procedures may be adaptable to that forum.
4.2 Robotic Manipulation

The demand for improved surgical performance and less perioperative morbidity has led to an explosion of new minimally invasive surgeries. Despite these significant innovative techniques reducing morbidity, some of these procedures remain very difficult even in the most experienced hands. This has led some researchers to evaluate the use of surgical robotic systems in hopes of making these more complex procedures more reproducible and efficient. Robots have greater spatial accuracy, are more consistent, more reliable, and can achieve greater precision than human’s alone (13). This field is currently a very active field of research and represents one of the new frontiers in surgery. Robotics has been successfully used in the Orthopedic and Neurosurgery fields where fixed landmarks have aided in registration of the robotic devices (14-16). Despite initial success with some early devices, the response to automation in the operating room is one of concern and doubt, despite the fact that robots designed for surgery have been shown to out perform humans in some tasks.

In Urology, one of these minimally invasive techniques that can benefit from consistency and precision is the development of percutaneous access into the intra-renal collecting system. Many different urological procedures require this task as the initial step, however, even in the best of hands reliable access is not assured. For this reason the PAKY robot was developed and perfected. Cadeddu et al. demonstrated the accuracy of the PAKY system in ex vivo porcine kidneys with contrast filled collecting systems; this system successfully accessed the targeted calyx on the first attempt 83% of the time. In vitro performance experiments demonstrated a mean distance error (accuracy) of less than 0.50 mm (8,17).

With the immense interest in telemedicine applications and the desire to project medical expertise to remote areas, a TelePAKY application was developed. This robot represents the first system for actively performing a remote telesurgical intervention in the kidney and demonstrates the feasibility of safely assisting accurate and rapid needle access to the kidney during percutaneous procedures. Furthermore, this technology allows an experienced mentor to actively participate in a remote surgical procedure (telerobotics) as well as guide and instruct an inexperienced surgeon through a procedure (telementoring). This technology can potentially enhance surgeon education; increase patient access to experienced surgeons and decreases the likelihood of complications due to inexperience with new techniques. This type of health care delivery has already demonstrated several significant advantages. First, telemedicine increases patients’ access to physicians. Individuals in remote areas and in emergency situations could rapidly obtain health care. Moreover, patients will have access to experts worldwide in all medical specialties. Individuals with rare diseases could quickly find physicians with expertise treating their specific ailment. Finally, obviating the need for patient/physician travel as well as eliminating redundant resources such as office space and personnel can decrease the cost of health care delivery.

An issue that still requires additional research is needle and tissue deflection during insertion. Innovative engineering research should focus on the development of hardware and control measures for preventing and accounting for this potential deflection of the needle as it passed through the tissue. In addition, research addressing the problem of needle registration and target triangulation based on portable x-ray fluoroscopy needs to be expanded. Additional imaging modalities such as CT, MRI and 3-D ultrasound require investigation for improved accuracy. The eventual goal is performing image guided robotic operations using the most accurate imaging modality in the operating room. With further refinement the PAKY robot has the potential to reliably improve results obtained with manual percutaneous access by increasing the accuracy of needle placement while decreasing the procedure time and complications.

This new generation of robotics may represent an initial advance towards a fully automated percutaneous system when combined with more advanced computerized imaging modalities. In addition, with its remote capabilities there may be a role for TelePAKY in teaching percutaneous access.

5. REFERENCES