Technology Insight: telementoring and telesurgery in urology

Ben Challacombe, Louis Kavoussi, Alexandru Patriciu, Dan Stoianovici and Prokar Dasgupta*

SUMMARY

The rapid expansion of the field of minimally invasive surgery has been accompanied by a number of controversies. These novel surgical techniques offer benefits to the patient with regard to length of hospital stay, return to full activity, and cosmesis; also, they are often more cost-effective than open procedures. On the other hand, they are technically demanding, have a significant learning curve, and can be associated with high initial complication rates unless performed by experienced endoscopic surgeons. Telemedicine, which uses real-time video and information transfer, offers the potential to increase the availability of minimally invasive surgery through video-assisted surgery and through remote instruction. At present, remote communities, especially those within developed countries, can most immediately benefit from telesurgical approaches. Enthusiasm must be tempered by the issues of cost, security, surgeon liability and availability of the technology itself which have yet to be fully resolved. In this Review, the field of telemedicine, focusing specifically on telementoring and telesurgery, and its relevance to urology are discussed. From early experimental work to current clinical usage, the advantages of and problems in this evolving field are explored.

KEYWORDS surgical robot, telemedicine, telementoring, telesurgery

REVIEW CRITERIA

PubMed and Medline were searched for papers published from January 1980 up to December 2005, under the terms "telemedicine", "telementoring" and "telerobotics". In addition, press releases and relevant national and international conferences were identified. Of the citations identified by the searches, papers were selected on the basis of relevance to the subject under review and impact within the field. Only papers published in English have been cited in this review.

B Challacombe is a Specialist Registrar in Urology, and P Dasgupta is a Consultant Urological Surgeon and Honorary Senior Lecturer, in the Department of Urology, Guy's & St Thomas' NHS Foundation Trust and Guy's, King's and St Thomas' School of Medicine, King's College London, UK. L Kavoussi is a Professor of Urology, A Patriciu is a Postdoctoral Fellow, and D Stoianovici is a Professor of Urology, at the Brady Urological Institute, Johns Hopkins Hospital, Baltimore, MD, USA.

Correspondence
*Department of Urology, Guy's Hospital, St Thomas Street, London SE1 9RT, UK
prokarurol@gmail.com

Received 25 October 2005 **Accepted** 6 September 2006
www.nature.com/clinicalpractice
doi:10.1038/ncpuro0626

INTRODUCTION

As surgical technology continues to develop, further roles and indications are found for the plethora of new devices across many medical specialties. Following a period of initial enthusiasm, during which these novel innovations are assessed in several potential roles, surgeons must address the challenge of deciding which of these surgical technologies are appropriate for long-term use and which are clearly not. Telementoring and telesurgery are examples of such new technologies, and they are ideally suited for use in the technology-heavy specialty that is modern urology.

Since the invention of the telegraph and the telephone, doctors have been able to communicate medical information over long distances. This was initially by voice, but more recently both email and the internet have enabled the transmission of images. Telemedicine is defined as 'medical care at a distance', and it incorporates the real-time communication of medical information between physicians in different locations. With the ever-increasing number of minimally invasive surgical techniques, including laparoscopic and robotically assisted surgery, there is huge potential to incorporate telemedicine techniques within this field. Procedures in which the internal organs are viewed by means of a television monitor are ideally suited to the transmission of video images to other sites. In addition, minimally invasive surgery, when performed by experienced surgeons, provides benefits for the patients themselves, the hospital and the operating surgeons. Patients could potentially benefit by receiving treatment from experts who they would not normally have access to, resulting in reduced length of hospital stay, earlier return to full activity, improved cosmetic results and a more precise surgical procedure. Hospitals themselves might have a reduction in overall operating costs through increased patient throughput, while surgeons can master complex procedures with the backup of an experienced mentor or remote assistant surgeon. A number

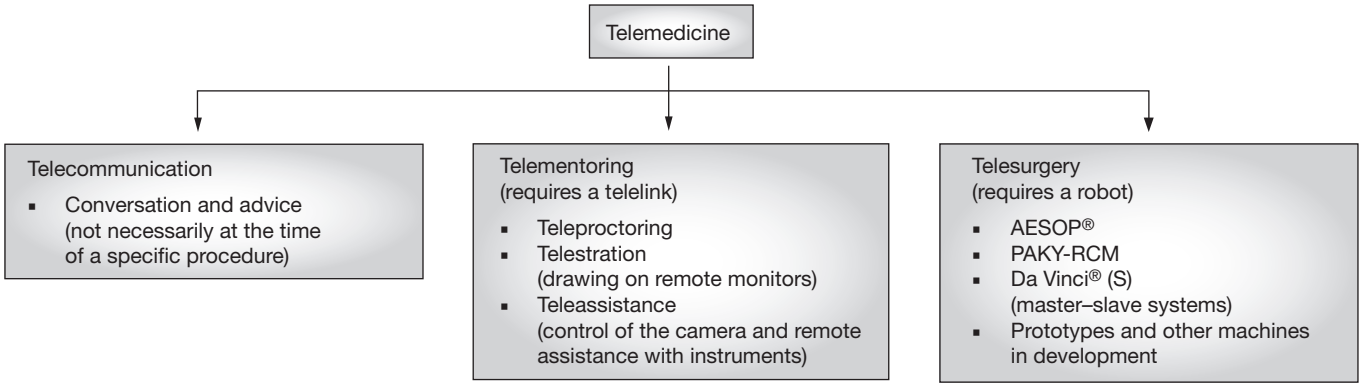

Figure 1 The three subdivisions of telemedicine. Telecommunication involves providing advice and no specialist equipment is required. Telementoring requires a telelink, but still primarily involves offering advice and guidance. Telesurgery requires specialist surgical robots and involves the surgeon conducting a procedure remotely. Abbreviations: AESOP®, Automated Endoscopic System for Optimal Positioning; PAKY-RCM, Percutaneous Access to the Kidney Remote Center of Motion.

of these techniques, such as laparoscopy, are difficult to master, and have associated complications that are inversely related to surgeon experience. The initial high complication rates associated with minimally invasive surgery and a lack of experienced endoscopic surgeons have raised concerns relating to training and, most importantly, patient safety. Telemedicine, in its broadest sense, might be the answer to some of these concerns. This article assesses the current state of the two main subdivisions of telemedicine: telementoring and telesurgery. Figure 1 outlines the main differences between the divisions of telemedicine.

TELEMENTORING

The term 'telementoring' is used to describe the guidance of one health-care professional (in this case a surgeon) by another in a different location during a procedure or clinical episode. The level of interaction from the mentor can be as simple as verbal guidance while watching transmitted, real-time video footage of the operation. In its more complex forms, it can involve indicating target areas on the local monitor screen (telestration), controlling the endoscopic or laparoscopic camera, or taking over as the assistant by controlling retractors and instruments via a robotic arm.

Technical considerations

To send an image between sites requires a network of communicating systems. This can be either a WAN ('wide area network'), running across the world, connecting countries and towns to buildings, or a LAN ('local area network'), running within a building or institution. To ensure security, the network path or connection should not allow other connections to or from it. This is a VPN ('virtual private network'), and provides a common path for video transmission. All networks now use the internet, and each individual station has a unique global address provided by the IP ('internet protocol') address. The internet itself has allowed huge advances in telemedicine and telesurgery as a result of its acceptance the world over.

Telementoring also requires a secure, high-speed internet connection with sufficient bandwidth to give a good picture quality at the mentor's station. The connection must transmit sound and vision in both directions. It has been shown that surgeons are generally able to compensate for delays (latencies) of up to 700 ms but delays above this are quite noticeable,[1] even though telementoring has been successfully performed with greater latencies. For remotely performing a surgical task (telesurgery), such as suturing with a robotic device, a delay of less than 250 ms is probably ideal for increased precision, although greater time delays have been shown to be acceptable. If using an integrated services digital network (ISDN) connection, a bandwidth of 384 Kb/s (six lines) is generally needed to give sufficient picture quality for accurate interpretation by the mentor, although clinical work has been carried out using bandwidths as low as 128 Kb/s.[2] For image quality analogous to the mentor being in the room far greater bandwidths are

required. To date only the Lindbergh trial, which used a 10 Mb/s bandwidth, transmitted images of this quality.[3] This lack of bandwidth and consequent reduction in image quality might partially explain the slow acceptance of this technology worldwide. An amplified audio connection is also required and sound quality is improved if the operating surgeon wears a headset microphone. Improved connections can allow the use of PACS (Picture Archiving and Communication System) images and other patient images while telementoring. Other links use an asynchronous transfer mode link which is faster than standard ISDN.

Security of the connection is vital, and encryption, which is now an established technology, is required for all systems, in addition to firewalls, within hospital LANs. Security measures, such as firewalls, will prevent hackers from entering the network and mean that acquiring direct access to the video stream is only theoretically possible. The use of firewalls is a matter of debate; some authors think that, rather than assisting in making telemedicine more secure, firewalls can present a barrier to telementoring.

Early uses of telementoring

One early use of telementoring involved the USS Abraham Lincoln Aircraft Carrier Battle Group, cruising the Pacific Ocean, and locations in Maryland and California, US (the Battle Group Telemedicine system).[4] Five laparoscopic inguinal hernia repairs were successfully completed on board the ships under telementoring guidance from land-based surgeons thousands of miles away. This work illustrated the potential for telementoring in the extreme environments of warfare and even, potentially, in space. In 1996, a group from Johns Hopkins Hospital, US successfully used an experienced mentor to supervise an inexperienced surgeon 300 m away. A robotic arm was used to control the video endoscope, and a telestrator was used to indicate important features on the surgeon's screen.[5] Telementoring was successful in 22 out of 23 cases, and the investigators concluded that operative times of basic procedures did not statistically differ between telementored and traditionally mentored procedures (but were longer for more advanced cases). Complex cases included laparoscopic heminephrectomy, bladder augmentation and laparoscopic ureteral lithotomy.

Around the same time as the Johns Hopkins experiment, another experiment compared locally mentored training with telementored training of surgeons in laparoscopic colonic resections and Nissen fundoplication. Performance outcomes did not differ between groups.[6] To illustrate the potential of telementoring in remote environments, a laparoscopic cholecystectomy and five preoperative evaluations at a mobile surgery unit in Ecuador were successfully telementored from the department of surgery at Yale University School of Medicine, US.[2] A collaboration between the John Hopkins group and an Italian group resulted in successful telementoring of geographically remote surgeons in procedures as advanced as laparoscopic nephrectomy.[7]

More recently, a renal transplant surgeon who was a relative novice at laparoscopy was able to initiate independent hand-assisted laparoscopic donor nephrectomy by means of international telementoring. There were no adverse events and graft function was excellent. The mean operative time was 240 min, the mean warm-ischemic time was 189 s, and the mean length of hospital stay was 3 days. Early results seemed to show that telementoring can significantly shorten the time taken to learn complex laparoscopic procedures and facilitate independent practice.[8]

Telesurgical telementoring

Following the success of earlier experience with telementoring, the John Hopkins group increased the distance to their remote site to approximately 5.6 km, while incorporating controls to a robotic arm that manipulated the laparoscope and access to electrocautery devices for tissue cutting or hemostasis during the telementored cases. They named this technique 'telesurgical mentoring'.[9] Using a similar set-up to the group at John Hopkins, the first international telesurgical mentoring procedure was performed in Baltimore, US and Innsbruck, Austria (laparoscopic adrenalectomy) and subsequently in Baltimore and Singapore (laparoscopic varicocelectomy), using three ISDN lines and a bandwidth of 384 Kb/s, and adapting for an approximate 1 s delay.[10]

The telesurgical telementoring equipment has been used by the group from Johns Hopkins to successfully telementor a laparoscopic bilateral varicocelectomy and a percutaneous renal access for a percutaneous nephrolithotomy between Baltimore and Sao Paulo, Brazil.[11] The remote surgeon controlled the laparoscope via an AESOP 3000™ (Computer Motion Inc., Goleta, CA) robot. In collaboration with the University

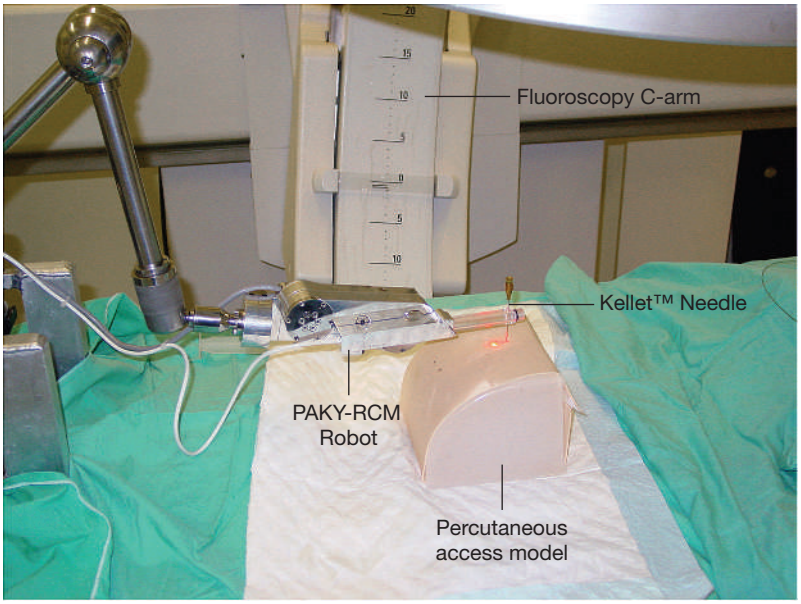

Figure 2 PAKY-RCM robot during a randomized, controlled trial of telerobotics. Abbreviation: PAKY-RCM, Percutaneous Access to the Kidney Remote Center of Motion.

of Rome, this group has now carried out over 17 telesurgical telementoring procedures.[12] These cases include laparoscopic varicocelectomy, nephrectomy and pyeloplasty, using AESOP 3000™ or the PAKY-RCM (Percutaneous Access to the Kidney Remote Centre of Motion) robot, designed and manufactured by the Robotics Department at Johns Hopkins University.

TELESURGERY

The next logical progression from telesurgical telementoring, where the mentor is not the primary surgeon, was to true telesurgery that is mainly or entirely controlled by a surgeon at a remote site. The first published example of the use of this technique was a transrectal ultrasound-guided prostate biopsy performed by Rovetta in 1995. In this case an SR 8438 Sankyo Scara™ robot (Adept Technology, Livermore, CA) mimicked manual handling of the transrectal ultrasound-guided biopsy device in the patient's rectum, in a telesurgery scenario.[13] This system did not become popular, probably because the benefits of telesurgery were outweighed by the increased cost and complexity of the robotic procedure (several thousand dollars, compared with less than US$100 for the manual procedure).

The US military were next to explore the potential of remote surgery, and developed a prototype remote telepresence surgery system with the aim of bringing acute surgical care to wounded soldiers in the combat zone.[14] This concept was supported by Satava, who foresaw a Mobile Advance Surgical Hospital with the capability for remote telepresence surgery.[15] The ideas for modern military surgery have been significantly developed in recent years, with the conception of virtual soldiers and the 'Trauma Pod' (an autonomous, mobile, roving surgical evacuation unit under development by the Defense Advanced Research Projects Agency),[16] although none are yet in clinical use.

With the introduction of the Da Vinci® and Zeus® robots (Intuitive Surgical, Mountain View, CA) the possibility of true telesurgery arrived. When using these master–slave systems, the surgeon sits at a console several feet away from the robotic arms. As a result, some have used the term 'telerobotic' when describing these devices. The first true (remote) telesurgical operation, however, was the Lindbergh procedure (a laparoscopic cholecystectomy) which was successfully carried out using the Zeus® robot with the surgeon in New York, US and the patient in Strasbourg, France.[17]

In 2002, a collaboration between a group at Johns Hopkins Hospital and one at Guy's Hospital, London, UK resulted in the first randomized, controlled trial of telerobotic surgery.[18] The authors compared manual with robotic and transatlantic telerobotic percutaneous needle access using a validated kidney model into which a Kellett needle was inserted 304 times (Figure 2). Half of the insertions were performed by a robotic arm and the other half by urologic surgeons. The order of needle insertion was random, except for a subgroup of 30 transatlantic robotic procedures that were controlled by the Johns Hopkins team via four ISDN lines. Although the robot-assisted insertions were slower than the manual insertions (35 s versus 57 s, respectively, $P<0.001$), they were more accurate, requiring fewer attempts for each successful needle insertion. These results imply that the robotic insertions were more accurate and reproducible (88% versus 79% success rate first attempt) than manual insertions.[19] In a second crossover trial, the telerobotic procedures were reversed, with the robot in Baltimore and the operators in London, with equivalent results for both time and accuracy (63 s versus 56 s, 1.2 versus 1.0 mean number of passes for success).

BENEFITS OF TELEMEDINE

Although telemedicine has great potential to benefit both patients and surgeons, its advantages remain largely unexplored. Remote surgeons and mentors can facilitate procedures that would otherwise not be attempted because of their complexity and a lack of available, experienced surgeons. They can also give guidance when unexpected intra-operative findings are discovered, such as abnormal anatomy, and can use their experience to assist in emergencies. The potential for litigation associated with some complex surgical procedures might decrease if surgeons have rapid access to advice from world experts in times of trouble. It is likely that the training period for new procedures will be shortened by telementoring, and operating times will subsequently decrease at a faster rate.

PROBLEMS WITH TELEMEDICINE

Despite the advantages associated with telementoring and telesurgery, a number of significant technical and ethical issues are raised by the continued development of technologies where surgical control or direction is remote to the patient. There can be no doubt that a surgeon's involvement with a procedure through a video link carries some liability. This is potentially compounded by the term 'mentor', which implies overall authority. Even advice over the telephone is potentially at risk of needing legal clarification with regard to liability. At present, medical qualifications from the European Union are not recognized in the US and vice versa. Also, surgical insurance policies for individual surgeons and institutions are usually specific to a country or even a region or state. When a surgeon in one country operates on a patient in another, several major ethical and medicolegal issues arise.

In the Lindbergh operation,[3] the surgeon obtained consent from the patient locally in France, before travelling to the US to carry out the procedure telerobotically. For international telerobotic surgery to become commonplace, special arrangements would need to be made for patient responsibility, and the remote surgeon, in addition to the local surgeon, would have to accept liability for the perioperative welfare of patients. This could take the form of a world telemedicine agency or authority, along the lines of the American Telemedicine Agency,[20] which, with appropriate insurance indemnity, could issue guidance on telesurgical procedures. Telementoring of novices by expert surgeons could be seen as part of the Continuing Medical Education program and be formally integrated into training pathways.

The security of the telecommunication links used in these procedures is vital, and there remains a risk of deliberate hacking and subsequent interruption or even interference during telesurgical procedures. With state-of-the-art firewalls and modern encryption, these risks are minimized. At some stage, hospital risk managers are likely to take an interest in the transmission of data that could identify the patient, which might lead to more specific patient and hospital-management consent being required.

Another issue is the reliability of the link itself, as it could be potentially disastrous to lose a connection at a critical operative stage. ISDN incorporates a secure system, as does asynchronous transfer mode, thus reducing the risk of interruptions to the connection; however, both require installation of specific cabling into the operating theatre, which consequently will drive up costs. The cost of buying a telecommunication system and installing cabling for a hard-wired connection currently stands at approximately $20,000 for a basic system. The operative cost of line rental from telecom companies would soon exceed this initial outlay, so it would be far more cost-effective to use the internet directly (with appropriate security). It would be logical for the local medical center to foot the bill for the telesurgical link, but this could financially prohibit smaller, remote medical centers (that stand to benefit most from such systems) from participating.

The future of telemedicine

As hospitals are modernized, it should be possible to install high-speed communication links or internet connections in all operating suites as standard. This will provide a ready-made LAN in each hospital. It will also be possible to expand this to a wide area network for regional or international connections. As links between institutions continue to grow, an internationally recognized telementoring pathway might result in an accredited qualification in surgical telementoring.

The development of robot-assisted surgery has in turn led to robotic telementoring. Anvari's group from Ontario, Canada, which has extensive experience with remote telementoring, has recently reported on 18 patients who underwent telerobotically assisted laparoscopic colorectal

surgery. They used bandwidths between 384 Kb/s and 1.2 Mb/s through telephone lines and a Zeus® robot to conduct remote surgery at a distance of 400 km. They reported good patient outcomes for the procedures that included bowel resection, Nissen fundoplication and splenectomy. There were no issues concerning quality or loss of signal and they concluded that telerobotic assistance was a significant enabling tool for this type of surgery.[19]

In 2005, Colonel Noah Schenkman of the Walter Reed Army Medical Center performed live telesurgery on two pigs at the American Telemedicine Association event. This was the first telesurgery using the Da Vinci® surgical system, the first procedure to use stereoscopic surgical video streaming, and the first telesurgery over the Internet. Surgeons in Denver successfully mentored surgical residents in California, using a 10 Mb/s connection to perform robotic-assisted nephrectomies.[21]

Surgeons interested in developing telementoring within their own institution are advised to contact one of the experts in their specific field, who has published in this area, in order to facilitate collaboration.

The operating room of the future is likely to involve robotic telemanipulation as one of a range of advances including robots (e.g. the new Da Vinci® surgical system), miniaturization, biosurgery (biotherapeutic and biomaterial products such as dermal fillers, autografts and larval therapies), and 'intelligent' instruments (e.g. bone-resection instrument guides).[22] New approaches to laparoscopy are undergoing animal trials, including the endoluminal and transgastric routes for cholecystectomy, appendicectomy and antireflux procedures.[22]

CONCLUSION

Within healthcare systems, it is logical to make use of all available resources, and surgical knowledge and experience are key assets. As the complexity of surgical technology continues to advance, the costs of hardware, software and telecommunication links will fall. The world is seemingly becoming smaller as a result of increased access to the internet and global travel, while patient expectations are rising. The field of international telementoring has steadily expanded, as opposed to exploding, over recent years. This slow expansion is probably the result of financial, ethical and medicolegal considerations, and of differences in software and hardware capabilities and specifications between individual countries. Unless these issues are resolved, perhaps by direction from an international body, telemedicine will fail to realize its full potential. The risks of security and liability need to be balanced by medicine itself, by proving that patient care is improved as a result of telementoring and telesurgery successes.

At present, telemedicine is ideally suited to use in developed countries with remote communities. Telementoring will allow dissemination of knowledge and skills, both nationally and internationally. All that remains is for urologists is to fully embrace these technologies, which they have already been pivotal in developing.

KEY POINTS

- Telemedicine has the potential to make a significant impact on urologic surgery and medicine in general
- International telementoring has already been used successfully for urologic surgery
- Telemedicine has not been taken up as quickly as predicted, despite initial enthusiasm, because of financial, technical and ethical issues
- Telesurgery has yet to fully overcome the problems of security, liability and the potential issue of confidentiality
- The formation of an international committee that would address these issues and coordinate global telemedical activity might aid further progress in this field

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Competing interests
The authors declared they have no competing interests.