Transcontinental Telesurgical Nephrectomy Using the da Vinci Robot in a Porcine Model

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OBJECTIVES Robotic telesurgery has been demonstrated over long distances and offers theoretical benefits to urologic training and the care of patients in remote regions. The multiple arms and three-dimensional vision of the da Vinci robotic system provide a platform conducive to long-distance telementoring and telesurgery. Whereas prior telesurgical efforts have used dedicated lines for information transmission, the public Internet offers a less expensive alternative. It was the intent of this study to test the validity of using the da Vinci system in urologic telesurgery, and to conduct telerobotic nephrectomies using the public Internet.

METHODS We performed four right nephrectomies in porcine models using the da Vinci robotic system. Telementoring and telesurgical approaches were used, with resident surgeons operating a console adjacent to the swine, while attending surgeons simultaneously operated a second console at distances of 1300 and 2400 miles from the operating room.

RESULTS All four procedures and both telementoring and telesurgical models were successful. Round-trip delays from 450 to 900 ms were demonstrated. Blood loss was minimal, and there were no intraoperative complications.

CONCLUSIONS This study represents the first use of the da Vinci Surgical System in urologic telesurgery and the first successful telesurgical nephrectomy in an animal model. UROLOGY xx: xxx, xxxx. © 2008 Elsevier Inc.

Whereas interest in performing remote surgery was first voiced by the National Aeronautics and Space Administration in 1972, the past decade has seen remarkable growth in the field of telesurgery.[1] In 1996, Cheriff *et al.* described six laparoscopic procedures in which a remote surgeon, 1000 ft away from the primary operating room, provided telesurgical consultation through audio contributions and video input by means of a telestrator, and by controlling the laparoscope via a robotic arm.[2]

The advent of more complicated surgical robots, such as the Zeus (former Computer Motion, Santa Barbara, Calif) and da Vinci (Intuitive Surgical, Sunnyvale, Calif) systems, have enabled remote surgeons to change their role from that of a telementor to that of a telesurgeon who actually manipulates the instruments performing the operation. Specifically, in 2001, Marescaux and colleagues reported the successful completion of transatlantic robotic cholecystectomies in 6 pigs and 1 human using the Zeus system.[3] The New York-based surgeon controlled the robot located in Strasbourg, France, over a dedicated fiber-optic network. The report by Anvari *et al.* in which he documented the routine use of robotic telesurgery over a distance of 500 km marked telesurgery's transition from an experimental novelty to a clinical reality.[4] A Zeus system with a private network (15 mb/s) was used for these 21 procedures. Demonstrating the clinical utility of telerobotic surgery, this affords an example of a centrally based tertiary care surgeon assisting in the care of patients in a remote, rural area. In addition to providing care in remote areas, the potential benefits of developing telesurgical systems extend from military and government uses, to improving resident training at smaller hospitals, and providing needed assistance to surgeons engaging in unfamiliar or complicated laparoscopic procedures.

Following these previous examples, we report the first instances of transcontinental urologic telesurgery performed using the da Vinci system. Furthermore, to our knowledge, this is the first application of robotic collaborative telesurgery in urology with two consoles engaged simultaneously, as well as the first urologic telesurgery performed over the public Internet using nondedicated lines.

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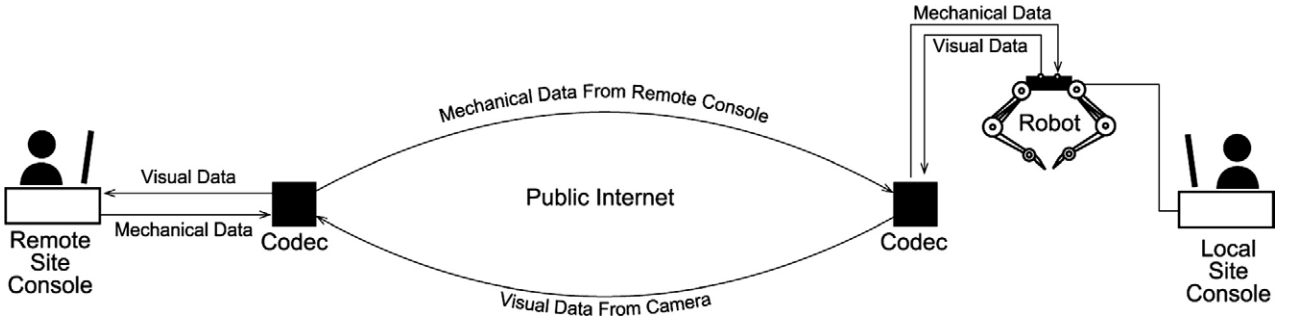

Figure 1. ●●●

Table 1. Results summary

	Network	Distance	Round-Trip Delay	Bandwidth Available/ Used (MB/s)	3-Dimensional Vision
Cincinnati to Sunnyvale	Public Internet	2400 miles	900 ms	3/2.6	Intermittently poor
Denver to Sunnyvale	Public Internet	1300 miles	450 ms	8/5.3	Good

MATERIAL AND METHODS

Four swine underwent da Vinci telerobotic right laparoscopic nephrectomies. In each case, the animal subjects and the robot were located in Sunnyvale, California, while the remote surgeon was located in Cincinnati, Ohio (March 21 to 23, 2005) or Denver, Colorado (April 17 to 19, 2005). In all cases, the onsite surgeon was a junior urology or general surgery resident experienced in obtaining intraperitoneal access in a porcine model, whereas the remote surgeon was an attending urologist or general surgeon trained in laparoscopy.

A da Vinci console was located at both the local and remote locations. For one of the four surgeries, the local junior surgeon controlled 2 of the robot's 3 operative arms, whereas the remote surgeon controlled 1 arm. Those roles were reversed for the remaining three procedures, with the remote surgeon controlling 2 of the 3 arms. The local surgeon controlled the electrocautery via a foot pedal for all four cases. A bedside surgical assistant manually controlled a suction device placed through a standard 10-mm laparoscopic port.

Video and robotic signals were carried over the Internet using nondedicated telecommunication lines. Two T1 lines were present at each site. The Internet service provider was Cincinnati Bell. Commercial video coding/decoding systems (CODECs) were used to code and decode the video and robotic information before and after transmission across the Internet. A CODEC converts video information into packets that are then sent via the Internet to a second CODEC which then decodes the packets, converting the information back to a video format. The first two surgeries were performed with CODECs from Polycom (Pleasanton, Calif), and the final surgeries were performed with Haivision CODECS (Montreal, Canada). The Polycom CODECs are designed for video-teleconferencing, whereas the Haivision CODECs were tailored to the specific needs of this project. Figure 1 details the experimental design.

Both surgeons' consoles provided three-dimensional (3D) video. The surgeons maintained verbal contact with one another via a standard telephone line with audio headsets and speakerphones. There were video cameras at each site that provided video feed into the opposite location to enable the surgeons to communicate visually when required.

These experiments were conducted under an IACUC-approved protocol. Each animal was under the care of a veterinarian at all times. The swine were monitored noninvasively while anesthetized and were euthanized immediately after completion of each procedure.

RESULTS

We successfully completed all four procedures. In each case, the setup, including the intraperitoneal access, proceeded without difficulty. In one of the Cincinnati-based procedures, there was a significant amount of visual packet loss (periodic, brief losses of video which result in a pixilated image) which obscured movement of the surgical arms, mandating that the distant surgeon act in a mentoring role, while the local surgeon completed the bulk of the procedure. The remaining three procedures were completed without such video loss at the distant site, and the distant surgeon was therefore able to complete the surgery while the local surgeon assisted with the use of one arm.

Table 1 lists the round-trip delay times, available and used bandwidth, and subjective quality of 3D video. A program developed by one of the authors (BCH) calculated the delay time. Though not recorded, blood loss from each nephrectomy was minimal, and there were no intraoperative complications.

COMMENT

These four nephrectomies represent the first time that the da Vinci robotic system has been successfully used in urologic telesurgery, the first time that collaborative robotic telesurgery has been performed in urology with two separate consoles controlling different parts of the same robot, and the first time that urologic telesurgery has been conducted over nondedicated Internet lines. Whereas these represent important firsts, these initial results also demonstrate that this system requires some

improvement before it can achieve the clinical utility demonstrated by Anvari's use of the Zeus system.[4]

One of the major benefits of telesurgery is the ability to engage in telementoring and instruction. Previous authors describe arrangements in which a remote, experienced surgeon mentored a junior surgeon performing laparoscopic procedures by means of audio signals and video input with the use of a telestrator, and by controlling the endoscope via an AESOP robotic arm (formerly Computer Motion, Inc., Santa Barbara, Calif).[2,5,6] In our experience, the mentoring element of the procedures was beneficial. Provided that the attending surgeon had a clear video signal, he could perform the case with minimal assistance from his junior counterpart. The three working arms of the da Vinci provided an excellent teaching opportunity because both surgeons were engaged simultaneously, a condition not seen when only one console is in use. As such, our model may afford a means of shortening the learning curve in robotic surgery by enabling simultaneous control of different arms by a teacher and a student.

In the one instance in which the video reception at the distant site was intermittently poor, this could be compensated for by verbal communication from the local surgeon, whose visualization was excellent. Despite the limitations placed on the senior surgeon's ability to move his instrument and visualize the operative field well, the case was completed without complication. The improved packet loss and shorter round-trip delay experienced during the Denver nephrectomies was the result of increased bandwidth and tailored CODECs as previously described.[7]

The speed of transmission and the coding/decoding process must be maintained at a high level to minimize the delay from the time that the remote surgeon makes a movement with his console to the time that that movement becomes visible on his own screen. It has been stated that this delay should be less than 300 to 330 ms to maintain surgeon performance.[3,8] In our experience, the delay of 900 ms proved cumbersome but was overcome with deliberation by the distant surgeon. The delay of 450 ms was manageable.

In addition, it is critical that the transmission be maintained throughout the procedure because the loss of audio or visual contact during a procedure could have catastrophic consequences. Security of the connection must protect from outside tampering to avoid invasion of the patients' privacy or interference with the procedure itself. Commercial solutions for this issue exist and must be incorporated into any clinical telesurgery solution. Each of the prior telesurgical endeavors has used some form of a dedicated line to minimize outside interference or technical difficulties with the link.[2–7,9,10] Security from tampering and privacy concerns must be addressed before adopting Internet telesurgery in human patients. In addition, Internet connection failures can occur in nondedicated lines; consequently, systems to ensure against such failures should be in place.

The da Vinci robot had not been used in this capacity previously and our prototype urologic telesurgery model had some important limitations. The camera, electrocautery, and instrument clutch settings, under control of the operating surgeon in normal circumstances, had to be adjusted manually at the local site. This was due to engineering limitations in our system as well as safety concerns with the distant surgeon operating with a visual latency of 450 to 900 ms. This study's limitations are of a technical nature that could likely be overcome by further development of the da Vinci system for telesurgical purposes. Future improvements to the Internet such as Internet2 may make telesurgery more feasible; however, it was our intent to prove that this could be performed using the simplest available Internet access. Because this was a pilot study, we did not establish metrics to assess efficacy. As telesurgery is pursued in future multicenter studies, however, surgical efficacy and efficiency should be further studied.

CONCLUSIONS

Without question, the telesurgical era is in its nascent stages. Our report of successful collaborative transcontinental robotic telesurgery in a porcine nephrectomy model suggests that whereas several problems with telesurgery such as liability, responsibility, and information security have yet to be addressed, the potential benefits in the civilian, military, and public health sectors could be far-reaching. As such, telesurgical pursuits are worthy of urologists' continued energies.

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