Major Digestive Surgery
Using a Remote-Controlled Robot

The Next Revolution

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Hypothesis: A remote-controlled robot can be used to perform computer-enhanced major digestive laparoscopic surgery.

Design: Cases series for assessment of the feasibility and safety of this technology in major digestive surgery.

Setting: Tertiary care referral center.

Patients: Between September 5, 2001, and December 20, 2001, 5 patients (4 men and 1 woman; mean±SD age, 66±5 years) underwent laparoscopic sigmoidectomy, proctectomy, restoration of continuity after Hartmann operation, Whipple procedure, and right liver lobectomy. In each of the procedures, a remote-controlled robot was used to perform some stages of the surgery. During these stages, the surgeon was seated at a distance from the operating table and performed the surgery using the robot, which offers enhanced intracorporeal tool manipulation and spatial vision.

Results: Sigmoidectomy was the only procedure that was completely performed with the robot. For the other procedures, the mean±SD duration of robot use was 25%±10% of the operative time. Stages of colorectal surgery, retroportal dissection, 2 anastomoses during a Whipple procedure, hepatic pedicle dissection, and initial hepatotomy were performed using the robot. This technology facilitates laparoscopic anastomoses. The principal drawbacks were the time required for robot mobilization, absence of grip strength feedback, limited availability of adapted surgical tools, and the cost of the system. There was no mortality. Two of the 5 patients experienced complications, a postoperative ileus and unexplained sepsis after the Whipple procedure, both of which were treated medically.

Conclusions: For these procedures, laparoscopic computer-enhanced surgery seems safe and feasible. This introduction of computing to major digestive surgery opens the door to enhanced-reality surgery and new types of surgical education.

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CHURCHILL’S quotation summarizes well the state of the art in laparoscopic surgery. Laparoscopy has been the most important advance in digestive surgery in the last 2 decades, and the introduction of robotics will likely be the next revolution. Robotics and computer enhancement can restore and potentially exceed the 3-dimensional (3-D) intracorporeal mobility of open surgery that classic laparoscopy has lacked. This revolution will involve complex laparoscopic instruments visualized with a stereoscopic viewing system. The human brain will be unable to fully integrate this technology without a computer interface.

Robotics in the field of human digestive surgery was first introduced by Cadiere’s team in Belgium in March 1997, as a component of laparoscopic cholecystectomy. Since this introduction, only the results of robotics use in Nissen fundoplication and laparoscopic cholecystectomy have been published.

The aim of this study is to assess the feasibility and safety of using a remote-controlled robot in digestive surgery to perform procedures other than Nissen fundoplication and laparoscopic cholecystectomy. We describe herein 5 surgical procedures involving the left colon, rectum, pancreas, and liver that have been performed using robotically assisted laparoscopy in our institution.
METHODS

Between September 15, 2001, and December 20, 2001, 5 patients underwent laparoscopy in which a stage of the procedure was performed with a remote-controlled robot (da Vinci Surgical System; Intuitive Surgical, Inc, Mountain View, Calif). All of the procedures were performed by a senior surgeon (B.G. or C.D.) in the laparoscopic specialty unit, where more than 500 laparoscopic colorectal resections have been performed since 1992. Training sessions with the robot on animals (swine) and fresh cadavers were performed before human use. Informed consent was obtained from patients before participation in the study. Details about patient characteristics and indications for surgery are summarized in Table 1.

The surgical robot consists of a work unit (operating table component) and a control unit (the surgeon’s console), which are connected by a computer-based system (Figure 1). The work unit is placed near the patient. It includes 2 surgical arms and 1 camera arm. At the end of each surgical arm, the robot has articulated instruments with 6° extension of freedom plus grip. The instruments are passed through trocars and have a maximum diameter of 8 mm. Representative instruments available are monopolar cautery hook, tissue forceps, scissors, and ultrasonic dissectors. The camera arm, which supports a 12-mm high-resolution endoscope, has 4° extension of freedom. The image is transferred to the surgeon’s console by two 3-chip charge-coupled device cameras contained within the endoscopic camera head. The control unit is located at a distance from the work unit. It consists of a surgeon’s console with an integrated 3-D display stereoscopic viewer (Figure 2). The surgeon, not sterilized, is seated at the control unit with his or her eyes focused downward toward the operative field as viewed in the 3-D display. The surgeon’s elbows are placed on a smooth support in front of the robotic handles. The thumbs and index fingers of the surgeon’s hands are passed through 2 rings on each of 2 master manipulators, which are mobile in all spatial directions, including grip (Figure 2). To increase the precision of surgical movements, a scaling of motion between robotic handles and intraperitoneal articulated instruments can be selected. Unintended movement caused by human tremor is filtered by the system. The robotic instruments can be disconnected temporarily from the master handles by a foot pedal, to allow the surgeon to reposition his or

Table 1. Patient Characteristics and Indications for Surgery

<table>
<thead>
<tr>
<th>Patient No./Sex/Age, y</th>
<th>Previous Abdominal Surgery</th>
<th>Indication for Surgery</th>
<th>Surgical Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/F/66</td>
<td>Appendectomy, hysterectomy*</td>
<td>2 Episodes for diverticulitis</td>
<td>Left-angle mobilization, sigmoidectomy, and anastomosis</td>
</tr>
<tr>
<td>2/M/69</td>
<td>None</td>
<td>Rectal adenocarcinoma</td>
<td>Proctectomy and anastomosis</td>
</tr>
<tr>
<td>3/M/72</td>
<td>Hartmann procedure, cholecystectomy</td>
<td>Restoration of colic continuity</td>
<td>Hartmann reversal</td>
</tr>
<tr>
<td>4/M/68</td>
<td>None</td>
<td>Tumor of the ampulla of Vater</td>
<td>Whipple procedure</td>
</tr>
<tr>
<td>5/M/58</td>
<td>Left colectomy, right portal vein embolization</td>
<td>Synchronous colorectal liver metastasis</td>
<td>Right lobectomy</td>
</tr>
</tbody>
</table>

*All previous abdominal surgical procedures were laparotomies, except for patient 5’s colectomy, which was laparoscopic.
her hands in a more comfortable and ergonomic position at the console. The robotic camera arm is manipulated by pressing the camera foot-switch pedal. This locks the instrument arms and gives the operator control of the camera through the master manipulators.

At least 2 additional trocars are inserted by the assistant, who remains sterilized next to the patient. During the procedure, the assistant’s mission is to expose the operative field and to complete hemostasis if necessary. Rescue hemostasis and vascular control are performed by the assistant by means of a suction device, bipolar forceps, and application of clips or staples with a laparoscopic stapler.

**RESULTS**

**COLORECTAL SURGERY**

Initially, the da Vinci system was used for colorectal surgery (patients 1, 2, and 3) to assess its use in our laparoscopic specialty unit. Sigmoidectomy for colic diverticulitis, proctectomy for limited rectal cancer, and Hartmann reversal have been performed.

Sigmoidectomy was completely achieved with the robot only in the first patient. In the subsequent patients, only certain stages of the surgical procedures were performed with the robot, mainly because of the delay needed to move the work unit. Assembly of the robot required 30 minutes, and disengaging it required 15 minutes. Dissection of postoperative adhesions, for example, which requires frequent change of trocar location, was incompatible with the use of the robot. However, as detailed in Table 2, various stages of colorectal surgery were performed, and the results in patients 1, 2, and 3 summarize well the potential of robotically assisted laparoscopy in colorectal surgery. Restoration of continuity after a Hartmann procedure has been greatly facilitated by this new technology. Adaptation of tools for pelvic surgery has enabled robotically assisted lateroterminal colorectal anastomosis with 2 continuous layers of suture. Because of tip articulations that mimic the wrist’s upward, downward, and side-to-side flexibility, intra-corporeal and deep anastomosis knot tying can be easily performed with the robot. The mean ± SD volume of blood loss in the 3 patients was 400 ± 100 mL. The mean ± SD percentage of robot use (excluding time for installation) was 28% ± 16% of the procedure time.

The postoperative course was uneventful in 2 patients, and a postoperative ileus persisted until day 7 after surgery in patient 2. In the 2 patients with benign diseases, histopathological findings were normal. The pathological results after proctectomy for cancer in patient 2 demonstrated rectal adenocarcinoma with safe margins and no malignancy on 19 lymph nodes analyzed (1997 TNM classification, T2 N0). The mean ± SD length of hospital stay was 8.3 ± 5.0 days. At 3 months of follow-up, all 3 patients were asymptomatic.

**PANCREATIC SURGERY**

In patient 4, a Whipple procedure with pylorus conservation was planned for an isolated histologically proven malignant tumor of the ampulla of Vater. Biliary obstruction had been initially treated with endoscopic stenting. Except for the duodenojejunal anastomosis, the procedure was performed completely by laparoscopy. Dissection and resection, as described in Table 2, were performed mainly with monopolar scissors and bipolar forceps without the robot. The retroportal dissection and anastomoses were, on the other hand, completely performed with the da Vinci system. Assembly of the robot required 30 minutes, and disengaging it required 15 minutes. The pancreaticogastroanastomosis was performed with 2 continuous layers of suture and the terminolateral biliodigestive anastomosis with 3 continuous layers of suture. The resected specimen was removed in a plastic bag through a 5-cm midline incision. According to the pylorus conservation technique, a terminolateral duodenojejunal anastomosis was manually performed through the midline incision with 2 continuous layers of suture.

The operating time was 450 minutes, and blood loss was 600 mL. There was no perioperative transfusion. The percentage of robot use (excluding installation time) was 20% of the procedure.

The initial postoperative course was marked by sepsis related to a perioperatively documented biliary infection. Percutaneous drainage of diffuse intraperitoneal effusion performed at day 7 because of sudden clinical aggravation revealed a polymicrobial infection, but no amylase or bilirubin. This resolved with 1 month of antibiotic treatment and drainage, with parenteral alimentation. The histopathological findings showed a stage pT2 N1 adenocarcinoma with negative surgical margins. The length of hospital stay was 32 days. After 6 months of follow-up, the patient was clinically asymptomatic with normal biological and morphological assessments.

**LIVER SURGERY**

A right liver lobectomy was planned in patient 5 to remove 2 synchronous rectal liver metastases (maximal size, 50 mm) localized in segments VIII and IV, after 11 courses of chemotherapy. Ten months earlier, a laparoscopic left
coloproctectomy for colorectal adenocarcinoma with radiotherapy of a left lobe liver metastasis (2 cm) had been performed. For the chemotherapy and the type of resection planned, a right portal vein embolization had been performed 6 weeks before the hepatectomy.

The right lobectomy (segments IV, V, VI, VII, and VIII) was performed completely by laparoscopy. The previous laparoscopic resection had left no postoperative adherences. Preoperative data were confirmed by an initial sonographic examination of the liver with a laparoscopic probe. Tape was placed around the hepatic pedicle to perform a Pringle maneuver if necessary. The right liver was dissected from bottom to top from its diaphragm adherences up to the vena cava and right hepatic vein. This first stage was mainly performed with bipolar forceps and monopolar scissors. We were unable to use the robot during this stage because of the unavailability of bipolar forceps. Furthermore, the devices may have been too short to reach the operative field. In contrast, all of the dissection of the hepatic pedicle and vessels of segment IV was performed with the robot using tissue forceps and a monopolar hook. Assembly of the robot required 15 minutes, and disengaging it required 10 minutes. The right branch of the hepatic artery and portal bifurcation was dissected by the robot. The artery was sectioned between 2 clips applied by the assistant, and the right portal branch was stapled and sectioned using a laparoscopic stapler (Ethicon Endo-Surgery, Inc, Cincinnati, Ohio). The initial parenchymal transection, started on the right side of the umbilical ligament, was performed with an Ultracision device (Ethicon Endo-Surgery, Inc) and tissue forceps. The right bile duct was sectioned with scissors directly below the parenchymal transection in the hilar plate and closed using absorbable suture. The parenchymal transection could not be completed by the robot because the instruments were too short to reach the operative field. Clips were applied to large vessels and, particularly, the middle hepatic vein. The procedure was completed with stapling and sectioning of the right hepatic vein with a laparoscopic stapler introduced via the left trocar. The liver was removed in a plastic bag through an 8-cm suprapubic incision.

The operating time was 450 minutes, and blood loss was 250 mL. There was no perioperative transfusion. The percentage of robot use was 22% of the operative time. The postoperative course was uneventful. The histopathological findings showed 2 adenocarcinoma liver metastases of 6.2 cm maximal diameter with 0.5 cm of free margins. The length of hospital stay was 7 days. At 12 months’ follow-up, the patient was alive with a suspicion of lung metastasis.

### Table 2. Intraoperative Details

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Surgical Procedure</th>
<th>Surgical Stages Performed With the Robot</th>
<th>Duration of Surgical Procedure, min</th>
<th>Robot Use During Procedure, %</th>
<th>Blood Loss, mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sigmoidectomy</td>
<td>Left-angle mobilization, sigmoidectomy, and anastomosis</td>
<td>330</td>
<td>90</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>Proctectomy</td>
<td>Total mesorectum excision, dissection of rectum, and anastomosis</td>
<td>450</td>
<td>40</td>
<td>400</td>
</tr>
<tr>
<td>3</td>
<td>Hartmann reversal</td>
<td>Upper rectum dissection, colorectal anastomosis</td>
<td>360</td>
<td>16</td>
<td>500</td>
</tr>
<tr>
<td>4</td>
<td>Whipple procedure</td>
<td>Retroportal dissection and pancreatico gastric and biliodigestive anastomoses</td>
<td>450</td>
<td>20</td>
<td>600</td>
</tr>
<tr>
<td>5</td>
<td>Right lobectomy</td>
<td>Hepatic pedicle dissection, anterior part of hepatotomy</td>
<td>450</td>
<td>22</td>
<td>250</td>
</tr>
</tbody>
</table>

### Comment

The use of a remote-controlled robot to perform part of the surgical treatment in these 5 patients is a step toward a new type of computer-enhanced digestive surgery. The da Vinci system will likely be a principal player in this next surgical revolution. As described in several publications,1-5 its primary advantage is the restoration and 6° extension of freedom of the human hand that conventional laparoscopy with rigid instruments does not allow. This intracorporeal freedom facilitates suturing and knot tying, as described in patients 3 and 4. The ease in suturing is especially advantageous in deep locations, such as the pelvis. Recent application of the da Vinci system has been reported in urologic surgery, particularly laparoscopic radical prostatectomy.6 Digestive surgery and laparoscopic (and perhaps “classic open”) proctectomy also promise to be particularly well suited to this technology.

The system has some mechanical limitations. Its principal drawback is the absence of tactile and strength feedback of the forceps grip. Technical limitations preclude a rapid correction of this problem. Other drawbacks, such as the limited number of adapted surgical tools and the time required for installation of the work unit, should be quickly resolved by the manufacturer. A final limitation of this equipment is its price of approximately $1 million.

In addition to improved intracorporeal mobility, a principle advantage of the system is the similarity between the visualization of the operative field and that of open surgery. This serves to realize the dream of one reluctant surgeon, who said: “I will do laparoscopic hepatic surgery when I can introduce, not only my eyes or my hands, but all my head in the abdomen” (Henri Bismuth, MD, personal communication, June 1997). Computer-enhanced surgery will make laparoscopic major digestive surgery accessible to all surgeons, reserved until now for laparoscopic experts.

These technical advances in computer-enhanced surgery, already in use in urologic surgery and being tested in heart surgery, are opening the door to virtual surgery and enhanced-reality surgery, which previously were mere
Virtual surgery and enhanced-reality surgery, notably preoperative anatomic 3-D liver reconstructions, will likely pervade the field of major digestive surgery in the coming years. The marriage of this technology with a robot is particularly suitable because the computer, in contrast to the human, always knows exactly where it is in orthogonal space. Real-time 3-D virtual reconstruction, including localization of surgical tools, can be performed and displayed in the surgeon’s console control unit. These simultaneous virtual reconstructions allow the surgeon at any time to view the operative field with different magnifications and to locate surgical tools. This is made possible by 3-D reconstruction of preoperative morphological data and real-time mobilization of the image reconstructed on the actual organ. Furthermore, we predict that computer-enhanced surgery will transform surgical education. With a robot being controlled by 2 main units, a surgical student can operate under supervision, like a copilot and a pilot. By pressing a foot pedal at any moment, the senior surgeon, seated locally or at a distance may resume the operation in the event of student difficulty. Robotic surgical training can be performed on virtual models or animals. Virtual models constructed with specific patient data will allow experienced surgeons to practice and prepare for the actual surgery.

CONCLUSIONS

The use of a remote-controlled robot to laparoscopically perform some stages of major digestive surgery is feasible and safe. A principal advantage of robotic surgery is the increased maneuverability of intracorporeal tools. This facilitates the application of continuous layers of suture and knot tying, notably in deeper surgical fields. However, of primary significance is the door to enhanced-reality surgery and to a new type of surgical education that computer-enhanced techniques in major digestive surgery have opened.

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REFERENCES