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Telerobotic Laparoscopic Repair of Incisional Ventral Hernias Using Intraperitoneal Prosthetic Mesh

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ABSTRACT

Laparoscopic ventral hernia repair shortens the length of hospital stay and achieves low rates of hernia recurrence. The inherent difficulties of performing advanced laparoscopy operations, however, have limited the adoption of this technique by many surgeons. We hypothesized that the virtual operative field and hand-like instruments of a telerobotic surgical system could overcome these limitations. We present herein the first 2 reported cases of telerobotic laparoscopic ventral hernia repair with mesh. The operations were accomplished with the da Vinci telerobotic surgical system. The hernia defects were repaired with dual-sided, expanded polytetrafluoroethylene (ePTFE) mesh. The mesh was secured in place with 8 sutures that were passed through the abdominal wall, and 5-mm surgical tacks were placed around the circumference of the mesh. The 2 operations were accomplished with total operative times of 120 and 135 minutes and total operating room times of 166 and 180 minutes, respectively. The patients were discharged home on postoperative days 1 and 4. The surgeon sat in an ergonomically comfortable position at a computer console that was remote from the patient. Immersion of the surgeon within the 3-dimensional virtual operative field expedited each stage of these procedures. The articulation of the wristed telerobotic instruments greatly facilitated reaching the anterior abdominal cavity near the abdominal wall. This report indicates that telerobotic laparoscopic ventral hernia repair is feasible and suggests that telepresence technology facilitates this procedure.

Key Words: Robots, Telerobots, Robotic surgery, Telerobotic surgery, Telepresence, Laparoscopy, Ventral hernia, Incisional hernia, Laparoscopic ventral hernia repair.

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INTRODUCTION

The United States Department of Defense stimulated the development of telerobotics in hopes that in the future surgeons in remote locations could operate on wounded soldiers on the battlefield.[1] Ninety percent of all combat deaths occur before the wounded soldier can be evacuated to a military hospital or aircraft carrier. Indeed, few soldiers die after reaching these medical facilities.[2,3] As a result, the aim of telerobotic surgery was to permit surgeons to treat life-threatening injuries, particularly exsanguinating hemorrhages, on the battlefield before the soldier died.[4] In this scenario, a medic brings the wounded soldier into an armored ambulance that houses a robotic surgical system. The soldier is placed under the robotic arms. The surgeon sits at a computer terminal on the aircraft carrier or at a nearby military hospital that controls the telerobotic surgical system. The surgeon sees a virtual reconstruction of the soldier and ligates the bleeding vessels with the telerobotic surgical instruments. The first telerobotic operation was accomplished in 1991.[5] Bowersox and colleagues[6] first proved the feasibility of this concept for military applications with a prototype of a telerobotic system in 1998.

The Federal Drug Administration (FDA) has approved 2 telerobotic surgical systems for clinical use in the United States. Intuitive Surgical (Mountain View, California) manufactures the da Vinci Robotic Surgical System, and Computer Motion (Santa Barbara, California) produces the Zeus Robotic Surgical System. In both of these telerobots, the surgeon sits at a computer console that is remote from the patient. Currently, the FDA requires that the surgeon remain in the same operating room as the patient. The operative field is projected by 3-dimensional imaging systems. The surgeon acts as the master and the computer as a slave.[7] The computer consoles translate the motions of the surgeon's hands into motions of the remote telerobotic surgical instruments. The telerobotic surgical instruments function with articulated ends that move in concert with the motions of the surgeon's hands. These wristed instruments facilitate difficult laparoscopic maneuvers like suturing.

Himpens, Leman, and Cadiere[8] first demonstrated the clinical utility of telerobotic surgery in March of 1997. At that time, the team accomplished a telerobotic laparoscopic cholecystectomy by using a prototype of the da Vinci robotic surgical system. This team also reported the successful use of the da Vinci system for telerobotic laparoscopic gastric bypass[9], Nissen fundoplication,[10] and fallopian tube reanastomosis.[11] Since that time, others have reported the use of da Vinci for most other gastrointestinal operations including Heller myotomy, gastrectomy, splenectomy, distal pancreatectomy, and colectomy.[12-21] Similarly, Marescaux and colleagues[22] have used Zeus for telerobotic laparoscopic cholecystectomies.

In this article, we describe the first 2 reported telerobotic laparoscopic ventral hernia repairs with mesh. We used the da Vinci telerobotic surgical system to accomplish these operations. The 3-dimensional video imaging system facilitated the lysis of adhesions and passage of sutures through the abdominal wall. The wristed surgical instruments simplified the laparoscopic approach to the anterior abdominal wall, a task that is generally impeded by straight traditional laparoscopic instruments. We believe that telerobotic surgical systems address some of the inherent limitations of traditional laparoscopic surgery.

CASE REPORTS

Patient 1

This 63-year-old woman complained of pain from a lower abdominal recurrent incisional hernia. She had undergone an ovarian cystectomy through a lower abdominal transverse incision as a young woman. She subsequently underwent a total abdominal hysterectomy through the same incision. Six years ago, she required an emergency surgical exploration because of perforated diverticulitis. Her abdomen was explored through a midline laparotomy incision that extended from the pubis to above the umbilicus. A sigmoid resection was accomplished and an end-descending colostomy was constructed in the left lower quadrant. The colostomy was closed 3 months later again through the midline incision. Three years ago, an incisional hernia developed through the midline incision halfway between the umbilicus and pubis. This was repaired primarily with permanent monofilament sutures. Two years ago, the patient noticed a recurrence of the lower abdominal incisional hernia. Since that time, it has been increasing in size. During the last year, the patient heard bowel sounds originating within the hernia sack and developed intermittent episodes of abdominal pain. Her past medical history was significant only for polymyalgia rheumatica and a penicillin allergy. A physical examination found a healthy appearing, 5-foot 2-inch tall, 150-pound woman. Her physical examination was normal except for the incisions and incisional hernia on her abdomen. A 3-inch x 2-inch defect of the abdominal wall was palpable at the lower extent of the midline incision. This was the area at which the transverse incision crossed. The contents of the hernia were reducible. Preadmission tests including a cardiogram and chest x-ray were all normal. Because of the increasing size of the recurrent hernia and the recent onset of abdominal pain, the patient requested surgical repair of the recurrent incisional ventral hernia.

Patient 2

This 54-year-old man complained of pain from an incisional hernia near his umbilicus. The patient had undergone an anterior resection for a rectosigmoid carcinoma 5 years ago. The operation was accomplished through a midline incision extending from his umbilicus to his pubis. The surgery was uncomplicated. He was treated with adjuvant chemotherapy and radiotherapy for 1 year after his surgery. During this time, his weight dropped from 220 pounds to 147 pounds. Over the last 4 years, his weight has slowly climbed back up to 195 pounds. At present, the patient is free of disease. His CEA levels are normal. A recent colonoscopy did not disclose evidence of recurrence of disease at the suture line or identify any metachronous colorectal lesions. The patient's current job requires him to lift heavy boxes for shipping. Nine months ago, the patient noticed a bulge near his umbilicus in the previous midline incision. Since then, it has been increasing in size. Over the last 2 months, he has noticed bowel sounds within the incisional hernia and developed occasional episodes of crampy abdominal pain. The patient's past medical history was significant for asthma, hypertension, and gastroesophageal reflux. Each of these conditions was easily controlled with a single medication. He also reported a penicillin allergy. A physical examination found a healthy appearing 6-foot, 195-pound man. His physical examination was normal except for the incisional hernia. A 2-inch defect was found in the proximal extent of the previous abdominal midline incision. The contents of the hernia were easily reducible. The patient had read on the Internet about laparoscopic ventral hernia repairs with mesh and had referred himself for surgical treatment of his incisional

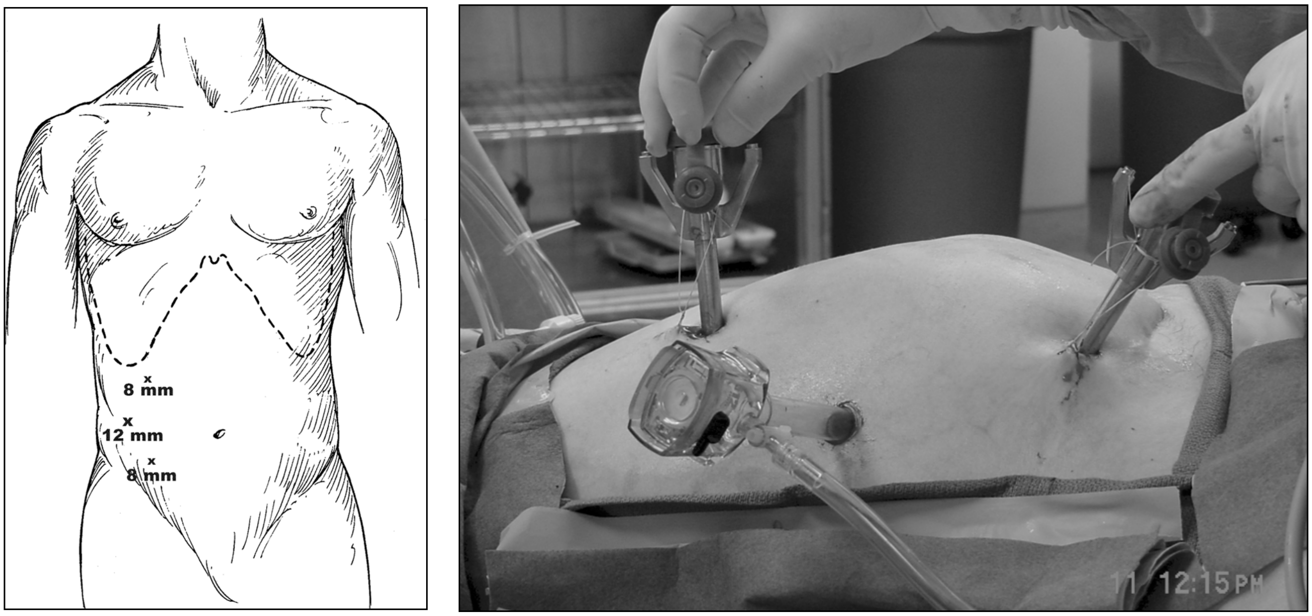

Figure 1. Three trocars are used in this procedure. A 12 mm disposable trocar for the stereo-optical telescope is inserted on the right anterior axillary line at the level of the umbilicus. Two 8 mm reusable trocars are inserted on the right mid-clavicular line. The right and left-hand instruments of the robot are inserted through these trocars.

ventral hernia. Prior to the development of his colorectal cancer, the patient was a body builder and wished to resume heavy weight lifting.

SURGICAL TECHNIQUE

Both operations were accomplished by using a similar technique. The patient was placed in a supine position. General endotracheal anesthesia was induced. An orogastric tube and urinary catheter were inserted. The abdomen was painted with an iodine-containing solution and draped in a sterile fashion. The patient was elevated into a reverse Trendelenburg position with the right side rolled up. Because both patients had undergone previous left colorectal operations, the trocars were inserted on the right side of the abdomen. The Veress needle was inserted 2 fingerbreadths below the right costal margin on the midclavicular line. A pneumoperitoneum was insufflated with carbon dioxide to a pressure of 15 mm Hg. A 5-mm disposable trocar (Ethicon Endosurgery, Cincinnati, Ohio) was inserted. The abdomen was inspected with a 5-mm, 30-degree telescope (Karl Storz Endoscopy America, Santa Barbara, California). Extensive adhesions between the omentum, small bowel, and previous abdominal incisions were observed in both patients. Bowel was incarcerated within the hernia sack of Patient 1 but not Patient 2. The anterior abdominal wall was free of adhesions on the right side of the abdomen in both patients. A 12-mm disposable trocar (Ethicon Endosurgery, Cincinnati, Ohio) was inserted on the right anterior axillary line at the level of the umbilicus **(Figure 1)**. An 8-mm reusable trocar (Intuitive Surgical, Mountain View, California) was inserted in the right lower quadrant lateral to the rectus sheath but anterior to the anterior, superior iliac spine. The 5-mm trocar in the right upper quadrant was replaced with another reusable 8-mm trocar. The patient was dropped into the Trendelenburg position with the right side still rolled up. The da Vinci Robotic Surgical System was advanced toward the surgical table at a 45-degree angle from the foot of the bed and attached to the 3 trocars **(Figure 2)**. The operation was observed with the 12-mm, 30-degree stereo-optical telescope (Intuitive Surgical) with the 30-degree angle turned up. The operating surgeon sat at the

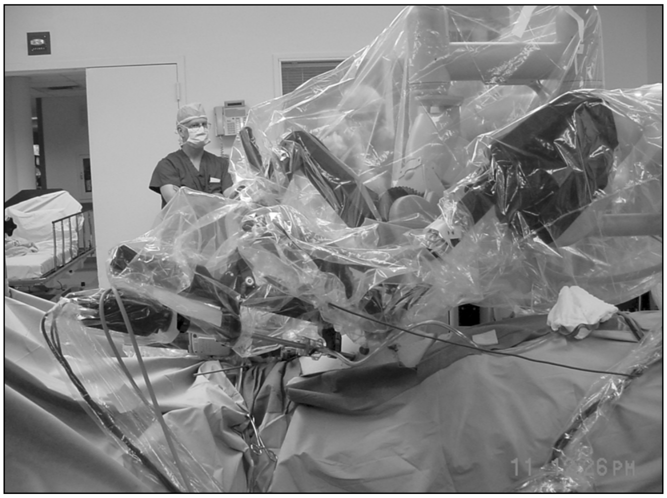

Figure 2. The tower that suspends the three robotic arms is brought in from the left side of the patient. It approaches the surgical table at a 45-degree angle from the foot of the table.

Figure 3. The small intestine was densely adherent to the anterior abdominal wall in Patient 2. Cadiere graspers in the robot's right hand provided traction on the bowel. Scissors in the robot's left hand divided the adhesions.

control console, which was positioned on the right side of the patient. This allowed the surgeon to observe the motions of the robotic arms and to help resolve any conflicts that developed between the motions of these arms. The bedside assistant surgeon was available also on the right side of the patient. The assistant observed the operation on a video tower positioned at the foot of the bed.

Telerobotic Adhesiolysis

Dissection was accomplished with a Cadiere grasper acting as the robots left hand, and an electrocautery hook was in the robots right hand. When the small intestines were tightly adherent to the abdominal wall or hernia sack, the adhesions were divided by using robotic scissors **(Figure 3)**. The Cadiere grasper was used to provide traction on the omentum or bowel while the abdominal wall provided countertraction. The bowel was freed from the hernia sack. All adhesions between omentum, bowel, and abdominal wall were divided. This left the anterior abdominal wall free of adhesions. This portion of the operation was accomplished in a solo manner by the surgeon operating at the surgeon's console **(Figure 4)**. The hernia sacks were left in place. The lining of the sacks was not cauterized or sutured.

Measuring the Abdominal Wall Defect

The bedside assistant surgeon identified the limits of the abdominal wall defect. The assistant surgeon passed a 2-inch needle through the abdominal wall. The passage of the needle was observed by the video camera. This technique permitted the assistant to accurately delineate the margins of the defect and mark these limits on the abdominal wall with a marking pen. We prefer the mesh to overlap the hernia defects with a 2-inch margin. Using a ruler, the assistant surgeon marked an additional 2-inch margin around the abdominal wall defects. This formed a rough ellipse around the abdominal wall hernia. In Patient 1, two defects were found. Both were through the previous abdominal midline incision. The total defect plus the 2-inch additional margin measured 11.3 x 8.2 inches (25 x 18 cm). In Patient 2, a single defect was observed through the previous midline incision. This defect and the 2-inch margin measured 6.8 x 6.8 inches (15 x 15 cm).

Preparing the Mesh

The defects were repaired with dual-sided expanded polytetrafluoroethylene (ePTFE) mesh (Gore-Tex DualMesh Biomaterial, W. L. Gore & Associates, Flagstaff, Arizona). The defect in Patient 1 was repaired with a 25 x 18-cm ellipse of this dual-sided mesh and that of Patient 2 a 15-cm circle. The head, foot, right side, and left side of the mesh were marked with a marking pen. Eight sutures of #0 polytetrafluoroethylene (W. L. Gore & Associates, Flagstaff, Arizona) were placed through the

Figure 4. The surgeon sits at the surgeon's console. The console is separated from the patient but required by the FDA to be within the same operating room. The console houses the robot's computer and binocular stereoscopic video system. The surgeon places his/her hands into the "master" (insert), which translates the surgeon's hand motions into the motions of the telerobotic surgical instruments.

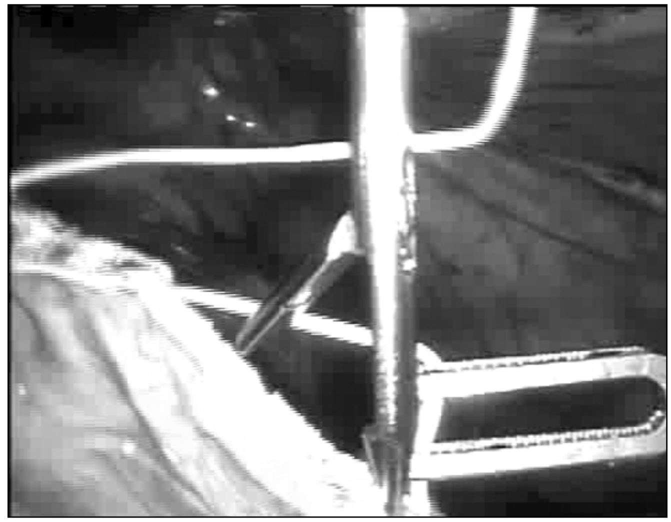

Figure 5. The bed-side assistant surgeon used a suture passer (Karl Storz Endoscopy America, Santa Barbara, California) to pull the #0 Gore-Tex suture (W. L. Gore & Associates, Flagstaff, Arizona) through the abdominal wall. The surgeon used a Cadiere grasper and needle holder to place the suture in the suture passer.

mesh at equal distances around its circumference. The needles were removed from the sutures, and the tails of each suture were secured to each other with a surgical clip. The pneumoperitoneum was deflated. The mesh was placed on the abdominal wall. Its perimeter was marked on the abdominal wall, and the position of each suture was indicated with the marking pen. The mesh was rolled up, and the sutures were contained within the tight cylinder.

Securing the Mesh in Position

The pneumoperitoneum was reinsufflated. In Patient 1, the 12-mm trocar was removed. The rolled up mesh was inserted through the abdominal wall defect caused by the trocar's insertion. Once the mesh was inside of the abdomen, the 12-mm trocar was repositioned. In Patient 2, the mesh passed easily down the lumen of the 12-mm trocar. Using the 3-dimensional imaging system of da Vinci, the surgeon unrolled the mesh. During this part of the operation, a Cadiere grasper was used in the robot's right hand and a needle holder in the left. The labels were used to orient the mesh. The bedside assistant passed the tails of the sutures **(Figure 5)** through the abdominal wall one at a time with a laparoscopic suture passer (Karl Storz Endoscopy America, Santa Barbara, California). A 2-mm stab incision was made for each pair of suture tails. The pairs of tails were secured together with mosquito clamps. Once all sutures were passed through the abdominal wall, the pneumoperitoneum was deflated to about half of its pressure. The mesh was pulled up to the abdominal wall and the sutures were tied. The rim of the mesh between the sutures was secured to the abdominal wall with 5-mm surgical tacks (Autosuture ProTack, Autosuture, Norwalk, Connecticut). This ensured that bowel could not pass between the abdominal wall and mesh between the sutures **(Figure 6)**. The pneumoperitoneum was deflated. The trocars were removed. The fascial defect of the 12-mm trocar was closed with 2 interrupted simple sutures of an absorbable suture. The skin incisions of the trocar sites were approximated with subcuticular sutures. Each wound was covered with an adhesive dressing **(Figure 7)**. The orogastric tube, urinary catheter, and endotracheal tube were removed at the end of both operations.

Operative Times

Patient 1: The patient tolerated the operation well. Blood loss was minimal. The patient was in the operating room

Figure 6. After the eight transabdominal wall sutures are tied, the edges of the mesh are secured to the abdominal wall with 5 mm tacks (Autosuture ProTack, Autosuture, Norwalk, Connecticut). This prevents bowel from migrating between the mesh and the abdominal wall. The mesh sits flatly against the abdominal wall covering the incisional hernia of Patient 2. The intraabdominal pressure is 6 mm of mercury during this portion of the operation.

Figure 7. Patient 1 at the end of the operation. Plastic dressings cover the three trocar sites on the right side of the abdomen and the eight 2 mm stab incisions through which the transabdominal sutures were passed and then tied. The margins of the two hernia defects are marked with small x's. Two concentric ellipses encompass the two defects. The outer ellipse marks the 2-inch overlap of the mesh around the hernia defects.

for 166 minutes. The initial incision was made 23 minutes after the patient entered the operating room. The duration of the operation from incision until placement of the dressings was 135 minutes.

Patient 2: The patient tolerated the operation well. Blood loss was minimal. The patient was in the operating room for 180 minutes. The anesthesiologist experienced difficulty intubating the patient and so the time between the patient entering the room and the initial incision was 47 minutes. The duration of the operation from incision to placement of the dressings was 120 minutes. The orogastric tube, urinary catheter, and endotracheal tube were all removed in the operating room.

Hospital Course

Patient 1: The patient experienced nausea and vomiting during the first postoperative night despite extensive administration of antinausea medications before, during, and after the operation. She developed a low-grade fever of 100.5°F that rapidly defervesced. The vomiting provoked a fair amount of abdominal pain. This was controlled first with parenteral then oral administration of narcotics. She was ready to be discharged home on the morning of the second postoperative day but developed a supraventricular tachycardia. This spontaneously converted to a normal sinus rhythm. The cardiology evaluation was normal but delayed her discharge until the fourth postoperative day. One month after surgery, the patient is continuing to progress rapidly. She has resumed her normal activities. She is retired and does not work. The incisional hernia repair is intact. No seroma has developed.

Patient 2: The patient remained afebrile. He experienced only a small to moderate amount of abdominal pain. This was easily controlled with oral narcotics. He was discharged home the morning after surgery. One month after surgery, the patient is continuing to do well. He has returned to work but is restricted from lifting heavy objects for another month. The incisional hernia repair is intact and no seroma has been observed.

DISCUSSION

We present here the first 2 reported cases of telerobotic laparoscopic incisional ventral hernia repair with mesh.

The surgeon sat at a console that was remote from the patient though the surgeon remained in the same operating room. The wristed telerobotic instruments facilitated the lysis of adhesions from the anterior abdominal wall and hernia sack. The angulation of the instruments permitted improved angles of attack towards the anterior abdominal wall as compared with that mandated by traditional straight laparoscopic instruments. The 3-dimensional video imaging system greatly facilitated the ability of the surgeon at the console to unroll the mesh, to orient it correctly, and then to assist the bedside surgeon in passing the suture ends through the abdominal wall. These tasks are often tedious and difficult when viewed with standard 2-dimensional laparoscopic imaging systems. In addition, the surgeon sat comfortably in an ergonomically advantageous position throughout the operation. We believe that telerobotic surgery overcomes many of the inherent limitations of traditional laparoscopic surgery and facilitates the performance of laparoscopic ventral and incisional hernia repair.[23]

These operations were accomplished within a virtual operative field. The da Vinci 12-mm telescope contains 2 separate 5-mm telescopes. The images from these 2 telescopes are broadcasted back to the surgeon's console and viewed through binoculars. The console is set up in such a manner that the surgeon perceives that he is immersed within a virtual operative field. Remote surgery of this kind has been deemed "telepresence surgery." Virtual operative fields address one of the inherent limitations of laparoscopic surgery. In traditional laparoscopy, the surgeon is forced to discern complex anatomy from clues imbedded in the 2-dimensional video image. In our experience, we find that this often leads to disorientation during complex operations. In contrast, we found that the virtual operative field projected by da Vinci greatly augmented the surgeon's ability to discern complex anatomical relationships. This, of course, greatly facilitated the operations.

Traditional laparoscopic instruments are straight. Because trocars are placed on the anterior abdominal wall, the surgeon often finds it difficult to perform delicate dissections and suturing on the anterior abdominal wall. The straight insertion angle of traditional instruments often does not permit the tip of the instruments to reach the anterior abdominal wall. The wristed instruments of da Vinci overcome this limitation of traditional laparoscopic instruments. Use of the angulation of these instruments permitted us to easily reach adhesions to the anterior abdominal and to dissect in various directions around them.

Incisional hernias develop in 3% to 13% of abdominal incisions.[24] Unfortunately, primary repairs of these incisional hernias often fail. Indeed, the rate of incisional or ventral hernia recurrence after primary repair ranges from 25% to 52%.[25-27] Rives[28] and Stoppa[29] developed a technique in the 1970s to address this high recurrence rate in which they place mesh beneath the rectus sheath and outside of the peritoneal cavity. Stoppa[29] has recently modified his approach so that complex hernias are repaired with an intraperitoneal placement of the mesh. This technique proved readily adaptable to a laparoscopic approach.

We learned the technique of laparoscopic repair used in these 2 patients from G. Voeller of Memphis, Tennessee.[30] Heniford, Park, Ramshaw, and Voeller[31] recently detailed their experience with this technique for laparoscopic ventral and incisional hernia repairs in 407 patients. Their average operating time was 97 minutes, which compares favorably with our operating times of 135 and 120 minutes. Similarly, Toy and colleagues[32] reported an average operating time of 120 minutes in 144 patients entered into a multicenter trial. The average hospital stay was 1.8 days for the patients of Heniford and colleagues and 2.3 days for those of Toy and colleagues. One of our patients went home on the first postoperative day, and the other was ready for discharge on the second postoperative day but developed a minor arrhythmia that delayed her discharge until the fourth postoperative day. These results suggest that even with our initial experience with telerobotic laparoscopic ventral hernia repair we were able to obtain clinical results similar to those of larger laparoscopic series.

Laparoscopic ventral hernia repairs with intraperitoneal mesh achieve low rates of hernia recurrence. During a mean follow-up time of 23 months, Heniford and colleagues[31] observed recurrence of the hernia in only 3.4% of their 407 patients. Toy and colleagues[32] identified 6 recurrences in their 144 patients, a rate of 4%, after a mean follow-up of 222 days. Similarly, Szymanski and colleagues33 observed a recurrence rate of 5% after 44 laparoscopic ventral hernia repairs. Although our initial experience with telerobotic laparoscopic ventral hernia repairs suggests that we can duplicate the technique described by these other surgeons, it will be some time before we can comment on the effectiveness of our repair.

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