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Robotic-Assisted Live Donor Ileal Segmentectomy for Intestinal Transplantation

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Background. Every effort should be made to optimize surgical techniques and to minimize potential morbidity rates associated with live donor operations. Advances in a minimally invasive approach by robotic surgery to donor nephrectomy have raised the possibility of applying this technique to live donor bowel resections for intestinal transplantation. **Methods.** We report the first 5 consecutive cases of a robotic-assisted live donor ileal segmentectomy. We describe the technical aspects of the procedure, discuss the rationale for considering this option, and evaluate potential advantages of this approach. **Results.** We found that this new approach is associated with less postoperative discomfort, a shorter hospital length of stay, and a faster recovery of bowel function compared to our previous open surgery. **Conclusions.** Our initial experience suggests that robotic surgery is a safe and feasible procedure for live donor ileal resection for intestinal transplantation and is a useful alternative to conventional open surgery.

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Intestinal transplantation (ITx) has increasingly become an accepted treatment option for patients with irreversible intestinal failure. Over the past 2 decades, ITx has shown remarkable advancement thanks to the progress in various aspects of organ preservation, surgical techniques, immunosuppression, and postoperative management.[1] Despite improvements in short-term outcomes, long-term survival of both patient and graft after ITx has been inferior to other solid-organ transplants, with a 10-year survival rate of less than 50%.[2,3] Allograft dysfunction and/or loss due to acute rejection and chronic enteropathy continue to pose major obstacles to the success of ITx.[4,5] Current knowledge indicates that both immune (antigen dependent) and nonimmune (antigen independent) events may promote intestinal graft injury.[6,7] A better understanding of the mechanisms for graft failure and the development of effective treatment protocols will help promote durable and long-term intestinal graft function.

To date, most intestinal allografts have been procured from cadaveric donors. Per the United Network for Organ Sharing, only 41 small bowel transplants (1.7% of the total) have been performed in the United States from live donors compared with 2400 from deceased donors.[2] Nevertheless, a living-donor bowel transplant has become a valuable source of organs in the absence of a suitable cadaveric donor. In addition, the use of live donor bowel allografts may potentially offer substantial advantages over cadaveric donors in terms of elective operations, better HLA matching, shorter waiting times, shorter cold ischemia times, and higher rates of immediate allograft function with acceptable risks for donors.[8] Current results suggest that patient and graft survival rates after live donor bowel transplants are similar or superior to those obtained with cadaveric organs.[9]

Open surgery for obtaining bowel allografts from living-donors was introduced by Gruessner et al,[10] in 1996, and since then has been the standard procedure for ITx.[9] Nowadays, minimally invasive surgery is increasingly being used to obtain a living-donor kidney, resulting in an increased acceptance of donor operations and the consequent expansion of the donor pool.[11-13] Surgical robots provide sharp 3-dimensional (3D) images, extended range of motion for the articulated instruments, and an optimal ergonomic environment for the surgeon.[14] These technically advanced features may potentially offer small bowel live donors less postoperative

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TABLE 1.

Donor demographics, operative characteristics, and clinical outcomes

Case	Age	Sex	BMI, kg/m^2	OP, min	DT, min	SCT, min	EBL, mL	WIT, min	CIT, min	Days to first flatus	Days to soft diet	Hospital stay, d
1	52	M	20.8	195	35	30	80	1.3	139	2	2	3
2	58	M	31.2	190	30	35	120	1.4	210	2	2	4
3	41	M	25.3	145	25	34	50	1.5	91	1	2	3
4	48	M	28.2	140	28	30	40	1.3	95	2	2	3
5	59	M	28.5	130	26	32	50	1.2	65	2	2	4

BMI, body mass index; OP, total operative time; DT, docking time; SCT, surgeon console time; EBL, estimated blood loss; WIT, warm ischemia time; CIT, cold ischemia time; M, male; F, female.

discomfort, faster recovery of bowel functions, shorter hospital stays, and improved cosmetics without compromising graft quality or procedure safety. To our knowledge, there have been no reported cases of robotic-assisted live donor bowel resection for ITx so far.

We describe herein, the first 5 consecutive cases of a robotic living-donor ileal segmentectomy, discuss the operative techniques, and evaluate the potential advantages of this new approach.

MATERIALS AND METHODS

Five consecutive live donors undergoing robotic-assisted ileal segmentectomies at our institution were included in this report from August 2015 to December 2016. Preoperative donor characteristics are shown in Table 1. A stepwise evaluation of live donors was based on the recommendations previously described by Testa et al.[8] Potential donors were initially screened based on patient history, physical examination, and ABO compatibility. In the event of multiple potential donors, the candidate with the best HLA-match was chosen. Conventional selective angiography or noninvasive angio-CT with 3D imaging reconstruction was used to evaluate the donors' superior mesenteric vessels before surgery. All 5 donors showed normal vascular distributions to the cecum, ileocecal valve, and terminal ileum (Figure 1A). After discussion of the various options for bowel segmentectomy, the donors agreed to undergo the robotic-assisted surgical procedure. This study was approved by our hospital ethics committee.

Mechanical bowel preparation was performed 1 day before surgery, and an oral antibiotic preparation, containing 1 g

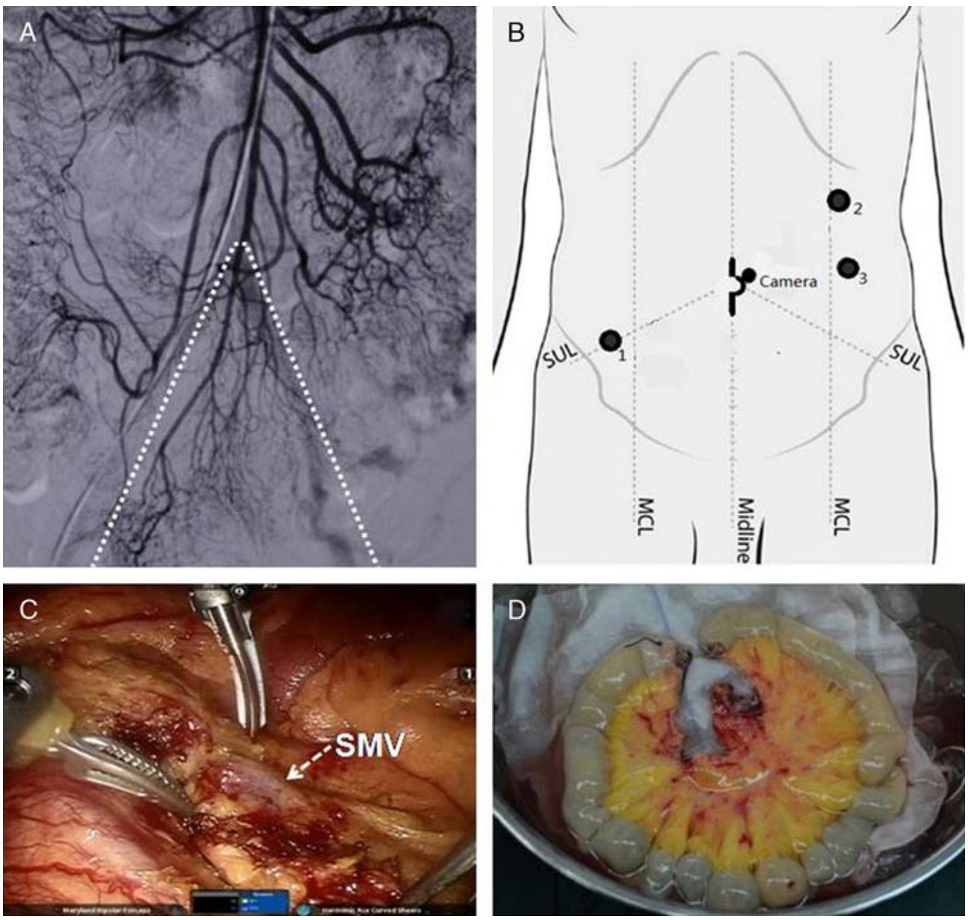

FIGURE 1. A, Selective angiogram of the SMA with jejunal and ileal branches as well as the ileocolic artery. Note the planned transection plane (the dotted line). B, Port placements for a robotic-assisted donor segmentectomy. C, Isolation of the SMV during operation. D, A perfused bowel graft in cold preservation. MCL, middle clavicle line; SUL, spinal umbilical line; SMV, superior mesenteric vein.

metronidazole plus 500 mg of neomycin, was given to the donors at 2:00 PM, 3:00 PM, and 10:00 PM. A single perioperative dose of antibiotic prophylaxis with 2 g of ceftriaxone was also administered intravenously.

The recipients received the induction therapy with a single dose of rituximab (375 mg/m^2) 2 days before surgery. Rabbit antithymocyte globulin at a dose of 1.5 mg/kg per day was initiated 1 day before transplantation and continued for 3 days thereafter. Postoperatively, the recipient was maintained on tacrolimus and prednisone with target trough levels of 15 to 20 ng/mL during the first month, 10 to 15 ng/mL during the next 2 months, and 8 to 10 ng/mL thereafter. For infection prophylaxis, the patient received piperacilline/tazobactam (6 g/day for 4-5 days), fluconazole (200 mg/day for 3 months), cotrimoxazole (80 mg/2 days for 6 months), and ganciclovir (900 mg/day for 3-6 months). Surveillance ileal biopsies were obtained twice per week. After hospital discharge, biopsies were taken once a week for the first 3 months, which decreased to once a month the first year in case of a favorable clinical evolution.

The donor was placed in the supine position, arms adducted. The urinary catheter, arterial and central venous lines were inserted under general anesthesia. Pneumoperitoneum (CO_2 at 12 mm Hg) was insufflated through a Veress needle and a 12-mm trocar for optics (Olympus, Karl Storz Endoscopy, Culver City, CA) was introduced slightly below the umbilicus, left of the midline. Once the intestine was visualized, an additional 12-mm trocar was placed on the right spino-umbilical line and 2 to 3 cm later to the crossing with the midclavicular (MCL) created for Maryland Bipolar Forceps. Another 8-mm trocar was inserted 8 cm below the left costal margin on the left MCL for Harmonic Curved Shears. A fourth 5-mm accessory trocar was placed slightly lateral to the left MCL to be used by the assistant for retraction/aspiration (Figure 1B). After trocar placement, the operating table was placed in a 30° Trendelenburg position and tilted to the left before docking the patient cart of the da Vinci robotic surgical system (Intuitive Surgical Inc., Sunnyvale, CA).

After a general exploration of the abdominal cavity, the greater omentum over the transverse colon and small bowel were pushed toward the upper left quadrant; the ileocolic vessels were identified by lifting the ileocolic junction. The nonvascularized area of the small bowel mesentery between the ileocolic artery and the superior mesenteric artery (SMA) was initially divided downward to the ileum edge and the ileal branch of the ileocolic artery was identified and divided. Then, the mesentery along with the superior mesenteric vessels was divided upward to the take-off of the ileocolic artery from the SMA. Next, the soft tissue around the superior mesenteric vessels was divided. The segment of the SMV draining the ileal graft was visualized slightly anterior to the right lateral of the SMA and was carefully dissected free for a length of 2 to 3 cm. The terminal branch of the SMA from the take-off of the ileocolic artery was identified and dissected free distally for a length of 2 to 3 cm. All the major branches of the SMA supplying the jejunum and proximal ileum were kept intact. At this stage, the use of the da Vinci robot was discontinued for the donor bowel segmentectomy.

The umbilicus port site was extended to a 6-cm longitudinal laparotomy. The entire length of the intestine was measured from the ligament of Treitz to the ileocecal valve. A 160- to 200-cm segmental ileum starting 20 cm from the ileocolic valve was selected, marked, and divided. The left side of the ileal graft mesentery was mobilized from the designed resection line of the proximal ileum towards the cut-off line of the terminal SMA in a "V"-shaped fashion (Figure 1C). At this point, a dose of 5000 units of heparin was intravenously administered 5 minutes before the SMA clamping and the division of the proximal ileum. Once the superior mesenteric vessels were cut at the designated line, the graft was immediately removed and flushed through its artery with histidine-tryptophan-ketoglutarate solution on the back table (Figure 1D). The 2 ends of the small bowel were approximated in an end-to-end fashion and the incision was closed in a standard fashion.

RESULTS

Donors

Total operative time ranged from 130 to 195 minutes with a surgeon console time of 30 to 35 minutes. Cold ischemia time ranged from 75 to 210 minutes with a warm ischemic time of 1.2 to 1.5 minutes (Table 1). Estimated blood loss was less than 120 mL. The transplanted bowel graft immediately returned to a pink color and regained active peristalsis after implantation (Figure 1D). Because of the shorter length and the presence of 2 branches of the SMV in donor 2, the right internal iliac vein of the recipient was procured and used as a Y-graft to reconstruct a single trunk SMV.

All 5 donors were directly transferred to the surgical floor with minimal surgical site pain, which was controlled by parenteral analgesics, and progressed to oral intake on postoperative day 1. They were discharged home on postoperative days 3 to 4, tolerating a general diet with no oral analgesics and resuming normal activities. None of the donors required blood transfusions during or after surgery. All 5 donors had mild diarrhea (3 to 5 bowel movements per day) during the first month, which decreased to 2 to 3 times per day by the second month after the procedure. Episodes of diarrhea were easily controlled with diet modifications and loperamide hydrochloride as needed. No surgical wound infections were seen.

Recipients

All the recipients were extubated after the transplant procedure, and transferred to the surgical ICU. The postoperative ICU stay was 2 to 4 days and the hospital stay was 20 to 30 days (Table 2). At a mean follow-up of 11.1 months (3.4-19.1 months), all 5 patients were doing well with no episodes of acute rejection and all were TPN-independent. The ileostoma was closed in 4 patients within 6 months posttransplant. Although low titers of non–donor-specific antibody (non-DSA) were detected in cases 2 and 5, it was cleared soon after transplantation. At the time of writing, no newly formed (de novo) DSA occurred in any patient (Table 2). Finally, no bacterial/viral infections or graft-versus-host diseases were diagnosed.

DISCUSSION

Minimally invasive surgical techniques have improved patient outcomes in many fields of surgery. Its indications have continuously expanded over the past few years. Robotic surgery is an innovative technology designed to facilitate minimally invasive procedures that require delicate tissue

TABLE 2.

Recipient demographics, operative characteristics, and clinical outcomes

Case	Sex	Age	Primary diagnosis	CMV D/R	ABO D/R	HLA D/R	PRA class I	PRA class II	Preformed DSA	Days to TPN-off	Hospital stay, d	Follow-up, mo
1	M	29	Volvulus	+/+	A/A	3/3	5%	0	None	10	20	19.1
2	M	24	Volvulus	+/+	0/A	3/3	16%	0	Non-DSA	12	28	12.6
3	M	18	Pseudo-obstruction	+/+	B/B	1/6	10%	0	None	14	25	11.9
4	M	57	SMA thrombosis	+/+	0/0	4/6	5%	0	None	21	28	8.7
5	F	63	SMA thrombosis	+/+	B/B	3/3	11%	67%	Non-DSA	14	30	3.4

CMV, cytomegalovirus; PRA, panel-reactive antibody; TPN, total parenteral nutrition.

manipulation. Nowadays, approximately 500 cases of robotic living-donor nephrectomy have been described, with excellent clinical outcomes and low morbidity rates.[12,15,16] A few cases of robot living-donor liver surgery and pancreas surgery were reported with encouraging results.[17-19] The available literature suggests that robotic surgery appears to be a safe surgical alternative to a standard open procedure and plays an increasing role in living-donor kidney procurement to improve outcomes and to encourage donation. Starting from January 2014, we have amassed an experience from 150 robotic-assisted colorectal resections, including 20 right hemicolectomies. Our initial experience in robotic surgery has been shown to greatly reduce patient discomfort allowing for earlier mobilization, hospital discharge, and return to work. These favorable clinical results prompted us to apply these advantages to live donor bowel segmentectomy for ITx. Our goal was to develop an operative procedure capable of reducing donor postoperative discomfort, hospital length of stay, and the potential incidence of surgical site infections associated with an open live donor bowel resection.

Open surgery requires an 8- to 10-cm length incision to allow for the isolation of the ileal portion and a good exposure of the mesenteric vasculature. In contrast, robotic surgery can be accomplished via 3 small transabdominal incisions and a 5- to 6-cm length incision to accomplish the same task. Although our donors did not suffer any surgical site infections, a wound infection associated with open surgery has previously been reported.[8] We anticipate that the potential risks of significant superficial and deep wound infections will be reduced in robotic surgery due to smaller incisions, greater surgical precision, and lower blood loss. Second, robotic surgery allows precise translation of the surgeon's hand movements in the operative field. A robotic approach has several advantages over a classic laparoscopic approach in performing precise dissection. The precision and dexterity of the wristed robotic instruments permit the operative procedure to be undertaken in a minimally invasive environment. The increased dexterity and 3D view of the system make it possible to attempt more complex procedures, such as isolation of the mesenteric vasculature. Third, the classic open approach can be safely performed in nonobese patients with a reasonable incision size and a minor risk of complications in experienced hands; however, this approach may be technically demanding in obese patients. In the absence of cadaveric donors or in the presence of a limited selection of live donors, an obese donor may be the only option. In case 2, the donor with BMI 31.2 kg/m^2 was an only candidate for live bowel donation. During the operation, we found an anatomic variation of the SMV in the designed cutoff line, which was not sufficiently appreciated by the preoperative selective angiogram. With the aid of the robotic system, we successfully isolated the 2 SMV in the heavy fatty tissue and later reconstructed a single trunk SMV on the back table. Finally, a shorter exposure time and less hand manipulation of the bowel graft may potentially reduce ischemic bowel damage and contribute to earlier bowel functional recovery.

Although donor safety remains a major concern for living donation, resection of a segmental ileum is relatively safe and is less complicated than the liver, kidney, and pancreas living donor procedures. In our previous 7 live donors with open surgery, the average exposure time of the ileal graft outside the abdominal cavity was 80 minutes compared with less than 30 minutes in our robotic cases; the median estimated blood loss was 250 mL compared to only 50 mL in the robotic cases; the median time to first flatus was 3 days compared with 2 days in robotic cases; the median time to soft diet resumption was 3 days compared with 2 days in robotic cases; and the median postoperative hospital stay was 5 days compared with only 3 days in our robotic cases. Thus, donor discomfort, hospital length of stay, and overall recovery time in robotic surgery can be markedly reduced compared with open surgery. Future effort will be required to confirm our preliminary observations. The improvement of postoperative discomfort and shorter recovery time may be valuable in encouraging living donation in the countries where organs from brain dead donors are scarce.

Although our initial experience with the robotic bowel resection was successful, there were some potential limitations to the procedure in terms of the prolonged operating time, the need for special equipment, and the overall high costs. This robotic surgical system became available in January 2014, and since then, we have mainly used the device for advanced colorectal surgery. Although our operating time for our initial robotic surgery was considerably longer than the routine operating time for open surgeries, additional experience allowed us to better define the necessary steps and sequences of the operation, which led to improved efficiency. With appropriate training of the operating room staff, the average robotic set-up time decreased from 60 minutes initially to 25 minutes. Once we had gained sufficient experience operating with the da Vinci Surgical System, we began our first case of a robotic-assisted ileal resection in August 2015 and found that the use of the robot slightly prolonged the operating time compared to the standard open approach. Additionally, a common criticism of robotic surgery is the increased cost associated with the use of the da Vinci Surgical System. Currently, the overall cost of the robotic-assisted ileal segmentation in our institution is around 11000 to 13 000 US dollars in terms of disposable instruments, which is slightly higher than the cost of open surgery (around 7000-9000 US dollars). We believe that the benefits, such as the reduction in postoperative discomfort, shorter hospital length of stay, and faster bowel recovery clearly outweigh the costs for this group.

In conclusion, our initial experience suggests that a robotic-assisted approach is a safe and feasible alternative to a conventional open procedure for live donor ileal segmentation. The potential benefits associated with this system are more precise and meticulous intraoperative skills, which may contribute to the reduction of postoperative pain, a shorter hospital stay, and a fast recovery of bowel function. We believe that with additional clinical experience and the continued development of robotic technology, robotic live donor bowel resection will become a very useful procedure for living-related small bowel transplantation in the near future.

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