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ORIGINAL ARTICLE

Robot-assisted renal transplantation in the retroperitoneum

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The authors have declared no conflict of interests.

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Summary

Minimally invasive surgery for renal transplantation is still under development. We employed the robotic surgical system to perform renal transplantation with a minimally invasive wound. The operation was performed with a Gibson incision and two working ports. The space for the transplantation was created by retroperitoneal dissection with the robot lifting the abdominal wall. Vascular reconstruction was performed with two robotic needle drivers. We successfully performed robot-assisted renal transplantation in five female and five male patients with an average wound length of 7.7 ± 1.04 cm. Nine of the renal allografts functioned immediately, but one with prolonged warm ischemia during the live donor nephrectomy had delayed function. The average creatinine level and estimated glomerular filtration rate at discharge were 1.31 ± 0.31 mg/dl and 58.2 ± 8.1 ml/min, respectively. All the transplants are currently functioning at 6.9 ± 3.9 months after operations. In conclusion, with robot assistance, minimal invasive renal transplantation can be performed successfully in the retroperitoneum.

Introduction

Renal transplantation has been established and performed via a curvilinear skin incision, approximately 18–20 cm in length, in the right (or left) lower quadrant of the abdomen for decades [1]. The external and internal oblique muscles are always divided, and wound complications could arise and lead to delayed hospital discharge, or even reoperation in a certain portion of patients [2,3].

Robotic technology has been widely applied in urological surgery to minimize surgical wounds and the associated wound complications. A robotic surgical system can provide articulated instruments and three-dimensional close-ups of the surgical field, allowing surgeons to perform delicate procedures in a limited space. However, vascular anastomosis through robotic arms can be technically demanding due to a lack of tactile feedback [4]. There are only limited reports of robotic renal transplantation in the literature, one with the traditional incision and the others with transabdominal approaches [5–8]. Gas-filling laparoscopic approaches in organ transplantation pose the problem of graft rewarming during vascular anastomoses. In addition, transabdominal approaches to renal transplantation actually risk graft torsion and eventually graft loss [9]. Therefore, we developed a gas-less extra-peritoneal approach for renal transplantation with a muscle-sparing incision. Herein, we present the first 10 cases of minimal invasive renal transplantation in the retroperitoneum with the aid of the daVinci surgical system (dVss; Intuitive Surgical, Sunnyvale, CA, USA).

Patients and methods

From July 2012 to June 2013, we attempted to perform robot-assisted renal transplantation in six female and five male patients in our transplant center. One female patient was excluded without the robotic system applied for reasons of severe adhesion around the femoral vessels, probably caused by repeated cannulation and infection. Before the operations, details of the robot-assisted renal transplantation process were thoroughly explained, and signed informed consent was obtained.

After general anesthesia, the patient was secured to the table and initially placed in the supine position, with their legs extended and abducted. A muscle-sparing modified Gibson incision as described by Yang and Ou was adopted [10]. Briefly, a Gibson incision was made in the right (or left) lower abdomen beginning from 1 cm above the pubic tubercle and curving upward parallel to the inguinal ligament. The skin incision for each patient ranged from 7 to 9 cm in length, depending on the BMI of the patients and the graft size. The external and internal oblique aponeuroses were incised along with the rectus sheath in the lower end to the incision. The transversalis fascia at the lateral border of the wound was then incised to gain full access to the retroperitoneal space. The abdominal muscles were then retracted upward to facilitate dissection of the preperitoneal as well as the retroperitoneal space. An extra-peritoneal space was created over the right (or left) lower quadrant from the midline of the abdomen to the exposure of the iliac vessels and from the umbilical level to the urinary bladder. The iliac vessels were dissected free with the lymphatics over the vessels ligated.

Two working ports (8 mm for the first two patients and 5 mm for the others) were created at the umbilical level: one just below the umbilicus and the other at the anterior axillary line. The patient was then placed in the reverse Trendelenburg position by 15 degrees and tilted 15–20 degrees to the left (or right) to elevate the operation side. The dVss was then placed to the patient's right side and docked into position; accessibility to the operation field by the assistant surgeon, who stood between the legs of the patient, was thus well preserved. The robotic arms were attached to the robotic trocars and set to lift the abdominal wall about 3 cm higher. A 30-degree endoscope was placed over the Gibson incision (Fig. 1a and b). Meanwhile, the graft kidney underwent the back-table preparations, with particular attention paid to potential bleeding vessels.

The kidney graft was then put into the extra-peritoneal space through the Gibson incision with the renal artery and vein cross-clamped with one bulldog each. Vascular control of the iliac vessels was conducted by the assistant surgeon applying DeBakey vascular clamps through the Gibson incision. With robotic EndoWrist needle drivers in both working ports, the renal vein and artery were anastomosed end-to-side to the external iliac vein and artery, respectively, using two half continuous sutures of 6-0 Gore-Tex. The motion scaling of the robotic system was set at 3:1. After the anastomoses were checked by removing the DeBakey vascular clamps, the bulldogs on the renal artery and vein were relieved by the assistant surgeon to revascularize the kidney graft. The remote surgeon then scrubbed in and relieved the dVss of the patient, and the uretero-vesical anastomosis was performed through the Gibson incision using the Gregoir-Lich extravesical technique.

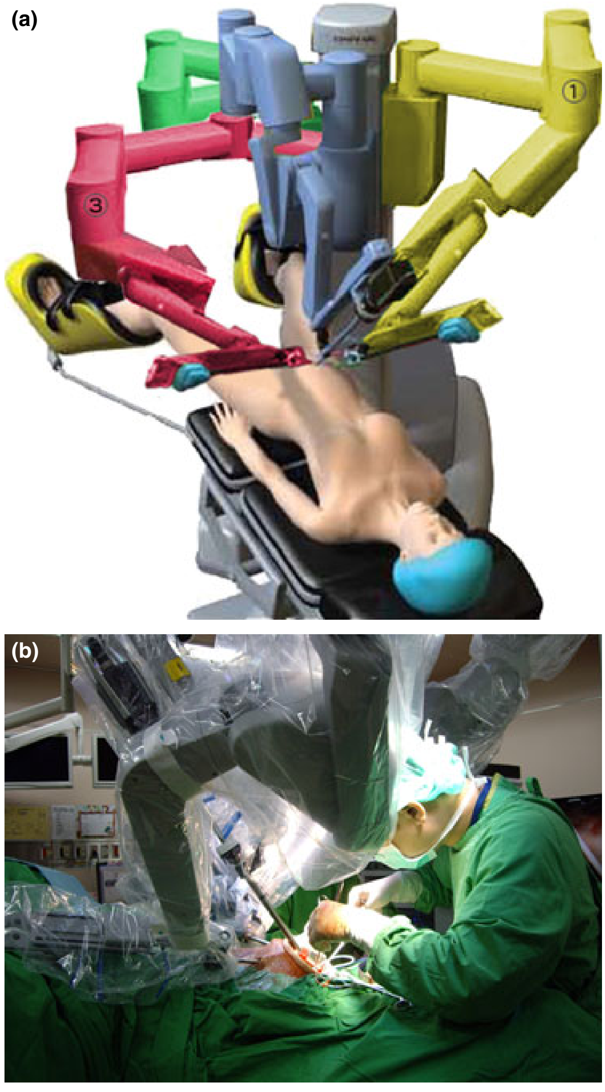

Figure 1 (a) Set-up and side-docking of the robotic surgical system for renal transplantation in the right side. (b) A representative picture of the robotic operation showing integration of the robotic arms, endoscope, and the assistant surgeon.

The immunosuppressive regimens in this series of patients were basically a calcineurin inhibitor, either cyclosporine or tacrolimus, combined with steroids, and an antiproliferative agent, either mycophenolate mofetil or mycophenolate sodium. None of the patients received antibody induction therapy. The doses of calcineurin inhibitors were adjusted to the target trough levels of 200–400 ng/ml

Table 1. Demographics of the patients and outcomes.

No.	Age Sex	BMI (Kg/m^2)	Donor/wound (cm)	Ischemia/anatomosis time (min)	Operation time (min)	Delayed function	Creatinine (mg/dl)	eGFR (ml/min)
1	60 F	20.2	L/7	310/94	229	No	0.9	47.9
2	21 M	24.0	L/8	325/111	341	No	1.8	65.9
3	61 M	27.9	L/9	346/81	330	No	1.3	64.3
4	46 M	23.3	D/8	620/68	255	No	1.1	74.9
5	49 F	19.4	L/7	310/46	258	No	0.9	56.9
6	55 M	28.2	D/9	712/67	312	No	1.4	62.4
7	41 F	21.5	L/7	240/44	232	No	0.9	66.2
8	26 F	19.5	L/7	208/47	187	No	1.2	56.1
9*	32 M	24.8	L/8	244/51	212	Yes	2.3	45.6
10	45 F	18.9	D/7	560/65	222	No	1.3	42.2

M, male; F, female; L, live donor; D, deceased donor; BMI, body mass index; eGFR, estimated glomerular filtration rate by the Cockcroft-Gault formula.

*Patient 9 received a live donor transplant with a prolonged warm ischemic time (190 s); the laparoscopic nephrectomy was complicated by instrumental failure in renal vein transection.

for cyclosporine and 8–12 ng/ml for tacrolimus. Mycophenolate mofetil or mycophenolate sodium was prescribed at initial doses of 1–2 g/day or 720–1440 mg/day, respectively. The white blood cell counts were controlled between 4000 and 6000/mm^3 unless intolerance developed or the maximum dose was reached. A bolus dose of methylprednisolone (10 mg/kg) was given before graft reperfusion with tapering to 20–30 mg oral prednisolone by day 8. The Cockcroft–Gault formula was used to estimate the estimated glomerular filtration rates (eGFR), with a correction factor of 0.85 for the females [11].

Statistical analysis

Continuous variables were presented as means with ranges, and BMI was kept as a continuous variable for analyses. The effects of BMI on anastomosis and operation times were studied by linear regression analyses using NCSS 2008 for WINDOWS software (Kaysville, UT, USA). The $P = 0.05$ level was adopted as the level of significance.

Results

The mean age of the 10 recipients with robot-assisted renal transplantation was 43.6 ± 13.8 years (range: 21–61 years). Their mean BMI was 22.8 ± 3.5 kg/m^2 (range: 18.9–28.2 kg/m^2). Nine of the renal allografts were from the left side: six from live donors undergoing laparoscopic donor nephrectomy and three from brain-dead deceased donors; one graft was from the right side of a deceased donor [12]. The kidney allografts were preferentially transplanted into the right iliac fossae except in two patients; one patient with a temporary dialysis catheter in the right femoral vein and the other with a peritoneal catheter in the right side had their renal transplants in the left side. The renal grafts had no vascular variations except for one with two renal arteries, which were joined side by side to share a common channel before anastomosis. The demographic data of the recipients and operations are summarized in Table 1.

The average skin incision was 7.7 ± 1.04 cm in length. One arterial and one venous anastomosis were performed in each of the 10 patients with robotic surgery, with an average anastomosis time of 67.4 ± 22.3 min (range: 44–111 min; Fig. 2) and an average operation time of 257.8 ± 52.7 min (range: 187–341 min). Linear regression analyses demonstrated that for every unit increase in BMI, there was an increase in the mean anastomosis time of 1.84 min ($P = 0.4243$) and operation time of 10.74 min ($P = 0.0234$). As the vascular anastomoses were checked with bulldogs applied to the graft renal artery and vein, none of the 10 patients had significant bleeding after vascular reperfusion. The average ischemic time was 283.3 ± 51.9 min (range: 208–346 min) for live donor transplantation and that for transplants from deceased donor was 630.7 ± 76.6 min.

One (Patient 9) of the 10 robot-assisted renal transplants had delayed graft function, which was resulted from prolonged warm ischemia (190 s) in the donor nephrectomy. The stapling devices failed to fire and transect the renal vein when the renal artery had been done. The renal vein was eventually divided after applying 2 hemo-o-lock clips and 3 hemoclips. Patient 9 received peritoneal dialysis during the first week and was discharged with a creatinine level of 2.3 mg/dl 20 days after transplantation. The average creatinine and eGFR of the 10 patients with robotic surgery were 1.31 ± 0.31 mg/dl and 58.2 ± 8.1 ml/min at discharge, respectively [11].

All of the patients with robotic surgery resumed oral intake and ambulation within 24 h after operations. The

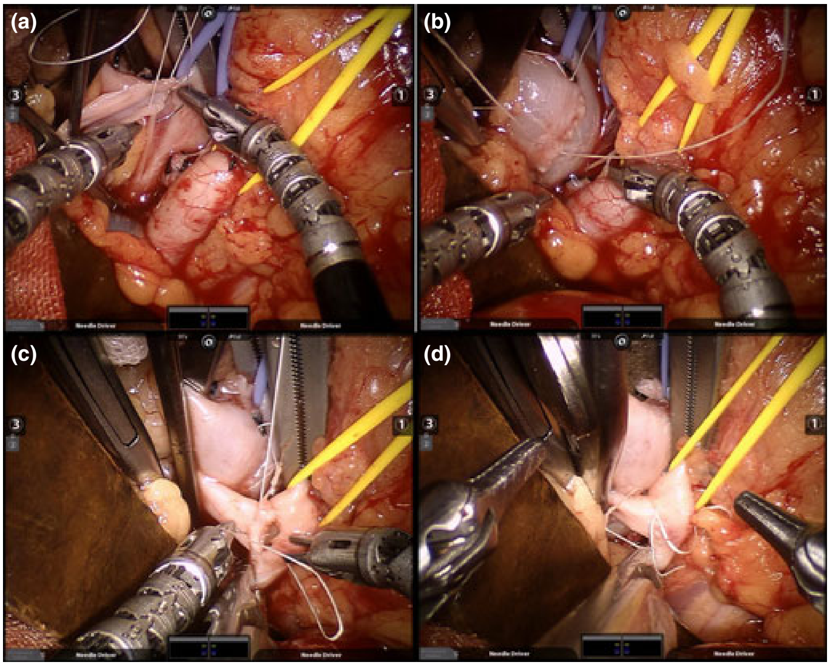

Figure 2 (a) venous anastomosis; (b) completed venous anastomosis; (c) arterial anastomosis; (d) completion of the arterial and venous anastomoses.

durations of hospital stay were within 14 days for all the patients but three: one with delayed graft function and the other two with overshooting tacrolimus levels taking 4 more days in the hospital to adjust. Overall, the average post-transplant hospital stay was 13.6 ± 3.5 days. After discharge, Patients 5 and 6 were re-admitted for management of acute humoral and cellular rejection, respectively. The humoral rejection was proved by renal biopsy with positive C4d staining, and Patient 5 was then rescued by plasmapheresis and intravenous immunoglobulin. None of the patients experienced any wound complications (Fig. 3). All the 10 transplants are currently functioning at 6.9 ± 3.9 months (range: 1–12 months) after operations. As for the patient who had open surgery, the creatinine level at discharge was 1.2 mg/dl and the eGFR 64.2 ml/min.

Figure 3 Operation scars 6 months after transplantation (right).

Discussion

Full laparoscopic approaches to minimally invasive renal transplantation using the dVss have been reported; however, transabdominal approaches of renal transplantation are not routine in conventional renal transplantation and can increase the risk of graft torsion and future biopsy-related injury [6–8]. Extra-peritoneal approaches to renal transplantation with limited incisions can be challenging because of an inadequate working space. We employed the robotic arms not only to conduct vascular anastomoses but also to lift the abdominal wall. Thanks to the EndoWrist instruments of the dVss, which offer a full range of motion; we were able to perform the vascular anastomoses in the retroperitoneal space created by lifting the abdominal wall. However, we assumed that the working space created by our extra-peritoneal approach was relatively limited in patients with a high BMI. We recommend not applying our extra-peritoneal approach to patients with severe morbid obesity.

Abdominal lifting has advantages over gas filling in terms of minimally invasive surgery for organ transplantation. Abdominal lifting can provide a working space for vascular anastomosis without sealing the abdominal wall, and warming of the graft can be prevented by frequent ice-saline irrigation through the Gibson incision. Frequent ice-saline cooling may also help to reduce the incidence of acute tubular necrosis [13]. In addition, suction can be freely applied to the operation field at the same time with no concerns of pneumoperitoneum. The Gibson incision also allowed for the application and fine adjustment of the vascular clamps and bulldogs during the vascular reconstruction. To secure the vascular anastomoses from bleeding upon graft reperfusion, we clamped the graft renal artery and vein by bulldogs before the graft kidney was placed into the recipient. The bulldogs were relieved via the Gibson incision after the anastomoses were tested and no leaks were found.

Robotic vascular anastomosis is technically demanding. An absence of tactile feedback may cause inadvertent needle or suture breakdown during continuous sutures. However, Hagen *et al* [14] postulated that the perception of haptic feedback can rapidly develop from visual clues that create an artificial tactile sensation in the brain. We feel that experience from microsurgical operations, which are too small to provide tactile sensations, may help to build the perception of haptic feedback. Having performed hundreds of murine heart transplantation for basic researches, we did not encounter much difficulty in performing robotic vascular anastomosis [15]. During our learning period, the anastomosis and operation times of the robotic approach were longer than those of the conventional approach. Although the risk of delayed function increased with prolonged anastomosis time, our only case of delayed function would be attributed to prolonged warm ischemia in the donor operation. As for hospital stay after transplantation, we did not expect patients with robotic surgery to have shorter hospital stay than those with traditional approach; patients could only be discharged with stable renal function and immunosuppression. We would expect our robot-assisted techniques to accomplish minimally invasive renal transplantation with comparable results to those of open surgery, as the case number and experiences accumulate.

Conversion to open surgery should be taken into consideration in the design of incisions for minimally invasive surgery. A periumbilical incision was adopted by Giulianotti *et al.* to perform robotic renal transplantation through the abdominal cavity, and Boggi *et al.* chose to perform the operation with a suprapubic incision [6,7]. Although conversion did not occur in their patients, a great extension of the incision seems to be inevitable when conversion to open surgery is indicated. Therefore, we placed our incisions for robotic renal transplantation along the line of incision for traditional transplantation to avoid additional incisions upon conversion. If conversion to open surgery is needed, the incision can then just be extended to the full length of the traditional incision. In addition, our Gibson incision provided a direct operation field for neoureterocystostomy. The ureteral anastomosis could be performed easily either by the robotic arms or by freehand.

Transperitoneal approaches, which increased the risk of percutaneous biopsy, might not be obligatory for the general adult population without morbid obesity. Actually, the prevalence of obesity varied among regions in the world; the incidences of obesity in patients of eastern countries were much lower than those in the western [16–19]. Patients without morbid obesity deserve well of minimally invasive renal transplantation in the retroperitoneum, where the risk of percutaneous renal biopsy was minimal [20,21]. However, patients of low BMI, as Keshore *et al.* [22] reported to be 20 ± 2.9 kg/m^2, might have incisions of 13 ± 1.7 cm in length allowing vascular anastomoses after placing the renal grafts in the retroperitoneal space. We would maintain that robotic assistance which provided relatively ample operation space and full range of sewing motion could benefit a renal transplant patient through an even smaller skin incision (7.7 ± 1.04 cm in our series). As for the cost of renal transplantation in Taiwan, the operation fees for conventional renal transplant surgery (about 2000 U.S. dollars) are fully reimbursed by the National Health Insurance. The additional charge for the robotic system in our hospital was <3000 U.S. dollars in every one of our renal transplant patients. We believe that a total cost of 5000 U.S. dollars would be reasonable for a renal transplant operation.

In conclusion, with abdominal lifting and vascular anastomosis by robotic arms, renal transplantation can be performed in the retroperitoneum with a limited skin incision.

Authorship

M-KT and C-YL: participated in the research design, writing of the article, performance of the research, and data analysis. C-YY and C-CY: participated in the performance of the research (donor operations). R-HH and H-SL: participated in research design.

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