Completely Intracorporeal Robotic Renal Autotransplantation

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Abbreviations and Acronyms

CT = computerized tomography

EIA = external iliac artery

EIV = external iliac vein

POD = postoperative day

RATx = renal autotransplantation

SCr = serum creatinine

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Purpose: We describe a technique of complete intracorporeal renal autotransplantation with donor nephrectomy and transplantation performed in a minimally invasive fashion without extracting the kidney.

Materials and Methods: We developed this technique of a completely intracorporeal robotic renal autotransplantation and determined the feasibility of this novel procedure. This includes a method of intracorporeal transarterial hypothermic renal perfusion using a perfusion catheter through a laparoscopic port. The procedure was successfully applied in a 56-year-old man with extensive left ureteral loss after failed ureteroscopy for ureterolithiasis.

Results: Robotic donor nephrectomy was performed with a warm ischemia time of 2.3 minutes. Subsequently cold ischemia was achieved by intracorporeal hypothermic renal perfusion for 95.5 minutes. Vascular anastomoses and ureteroureterostomy in the ipsilateral pelvis were completed after donor nephrectomy with a total overall surgeon console time of 334 minutes. Venous and arterial anastomosis times were 17.3 and 21.3 minutes, respectively. Estimated blood loss was less than 50 ml. There were no complications and the patient was discharged home on postoperative day 1 after normal Doppler transplant renal ultrasound. Postoperative renal scan at 6 weeks, intravenous urogram at 8 weeks and computerized tomography urography at 5 months revealed normal function and successful ureteral reconstruction.

Conclusions: We report the feasibility of a technique of a completely intracorporeal robotic renal autotransplantation. This operation may be considered in select patients in the hands of experienced robotic surgeons. However, further refinement is required as this novel procedure is cautiously reproduced and adopted by others.

Key Words: kidney; transplantation, autologous; laparoscopy; surgical procedures, minimally invasive; robotics

Renal autotransplantation was first described in 1963 to manage severe proximal ureteral injuries.[1] Since that initial description, RATx has been used for renal vascular trauma, thrombosis, stenosis and aneurysm as well as complex ureteral injuries, malignancies, urolithiasis, retroperitoneal fibrosis and loin pain-hematuria syndrome.[2] Although the conventional open approach to autotransplantation has excellent outcomes, it is performed through either a large midline xiphoid-to-pubis incision or through a flank incision for donor nephrectomy with a second pelvic incision for renal transplantation into the iliac fossa.[3] The significant

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morbidity and protracted convalescence of these open approaches have limited its use, especially in patients with another normal kidney.[4]

The advent of laparoscopic donor nephrectomy in conventional renal transplantation has stimulated renewed interest in RATx. By taking advantage of a minimally invasive approach to renal harvest the resulting decreased morbidity of autotransplantation despite an open pelvic incision may impact decision making between renal preservation vs nephrectomy.[4–6] Since it was first described by Fabrizio et al,[5] few cases of laparoscopic nephrectomy for open RATx have been reported.[2,6–10] After laparoscopic donor nephrectomy, in all cases autotransplantation was performed using an open technique through a separate incision or through the extraction incision used to remove the kidney.

While laparoscopy and robotic surgery have been used for donor nephrectomy[11–15] and in limited fashion for autologous renal transplantation,[15–18] to our knowledge RATx has never been performed in a completely minimally invasive fashion. If feasible, such a procedure would be unique in having no incision to extract or introduce the kidney. We developed a technique for completely intracorporeal robotic RATx and describe the first successful application of this concept.

MATERIALS AND METHODS

Patient

A 56-year-old man with coronary artery disease, hypertension and obesity (body mass index 34 kg/m^2) was referred after major left ureteral loss after endoscopic treatment of an obstructing stone. Unrecognized ureteral perforation and delayed recognition had resulted in a large infected urinoma. Ureteral stenting and percutaneous drainage were done. Several weeks later interval ureteroscopy and imaging revealed 12 cm of devitalized necrotic ureter (fig. 1).

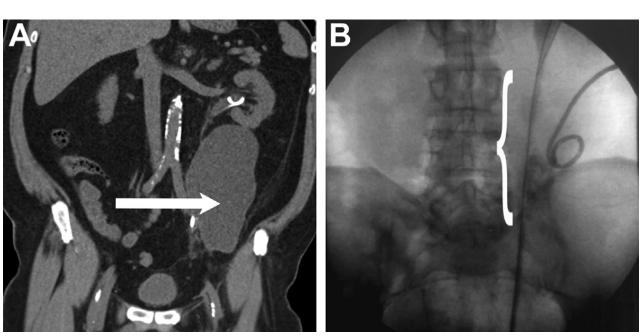

Figure 1. Preoperative images of injured ureter, including CT of infected urinoma (arrow, *A*) and retrograde pyelography after drainage showing 12 cm segment of strictured necrotic ureter (parenthesis, *B*).

The patient was counseled on management options, including nephrectomy, reconstruction using ileal interposition or RATx. Transureteroureterostomy was impossible due to the paucity of viable proximal ureter and, since he was a recurrent stone former, nephrectomy was undesirable. The patient elected RATx with ureteroureterostomy to the pelvic end of the ureter to preserve access through the native ureteral orifice for future stone management. This approach was also considered advantageous over bowel interposition because the injury length would likely necessitate 2 ileal segments (eg a double Monti) and 3 anastomoses.

The patient preferred a minimally invasive approach. He was counseled on minimally invasive renal harvest followed by open autotransplantation vs a completely intracorporeal approach. He elected the latter technique while understanding that open conversion might become necessary. The surgeon (RA) had trained in and performed renal transplantation before dedicating his practice to robotic surgery. The surgeon had performed more than 2,500 robotic procedures, including complex renal and renovascular surgery.[19,20] He also had limited experience with performing robotic autologous renal transplantation as part of a Vattikuti Urology Institute research protocol.[21]

Surgical Technique

The technique developed for robotic autotransplantation incorporates findings from the mentioned experience with autologous transplantation. However, it requires a method of patient positioning that allows access to the renal and iliac fossae as well as a method of intracorporeal renal hypothermic perfusion.

The procedure was performed transperitoneally using the da Vinci® Surgical System. Positioning was analogous to what we previously described for robotic nephroureterectomy, in which the bed and robot are repositioned without repositioning the patient.[22] Briefly, the patient was positioned supine with the legs in Allen stirrups and a gel roll behind the kidney (fig. 2, *A*). The

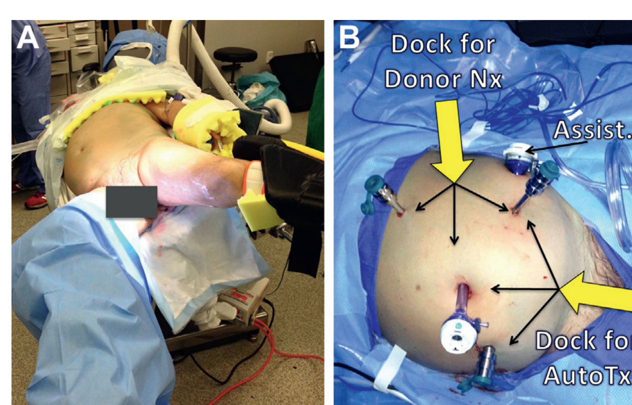

Figure 2. Patient positioning used for procedure (*A*), including bean bag and stirrups to allow transition from kidney approach to pelvis approach with repositioning of bed rather than patient. Placement of ports used for 2 operation phases (*B*). *Nx*, nephrectomy. *AutoTx*, autotransplantation.

bed was rotated to further elevate the flank during nephrectomy.

Five ports were used, including a 12 mm periumbilical camera port (30-degree down lens), an 8 mm port in each of the left upper quadrant, left lower quadrant and right lower quadrant, and an assistant 12 mm AirSeal® valveless port at the far lateral left lower quadrant (fig. 2, *B*). During donor nephrectomy robotic instruments were used through the left upper and lower quadrant ports. The right lower quadrant port was not used. For the pelvic portion of the procedure the umbilical port was used for a 0-degree camera. All 3, 8 mm robotic ports were also used. A ProGrasp™ was added in the fourth arm to position the graft for ideal proximity to the vessels for anastomosis and to place bulldog clamps. All dissection was performed using fenestrated Maryland bipolar forceps and monopolar scissors. All anastomoses were performed using large needle drivers and DeBakey forceps. Normal scale settings were used throughout the procedure.

Step 1—Left kidney harvest (robotic donor nephrectomy). The colon was reflected. The left renal vessels were dissected circumferentially to the level of the aorta to maximize length. The lumbar, adrenal and gonadal veins were clipped and divided. The kidney was completely mobilized. All perinephric fat was removed except that between the lower pole and ureter to maintain the ureteral blood supply. The ureter was dissected to the level of the injury and divided above the diseased segment, where normal caliber and mucosa were confirmed.

Ten minutes before renal vessel ligation 12.5 mg mannitol and 10 mg furosemide were given. The same perfusion cannula and tubing used during conventional donor nephrectomy at our institution (LifeShield™ Macrobore Extension Set, No. 12655-28) was introduced through the valveless port in preparation for intracorporeal hypothermic renal perfusion. After administering 3,000 U heparin the renal artery was ligated using robotic clips close to the aorta, followed by the renal vein in a similar manner. The renal artery and vein were then transected above the clips.

Step 2—Protective renal hypothermia. Immediately after dividing the vessels the perfusion cannula was inserted in the transected artery lumen, which was continuously flushed with ice-cold lactated Ringer solution under gravity until clear effluent was seen from the renal vein (fig. 3, *A*). Lactated Ringer solution was chosen because it is an effective alternative to more modern preservation solutions that contain high levels of potassium and other additives, which may be unsafe in the peritoneum.[23] The artery cuff was then secured to the cannula with a silk tie to allow for continuous hypothermic renal perfusion intracorporeally (fig. 3, *B*). The perfusion rate was titrated to enable a continuous visible flow of clear effluent from the renal vein with less than 1 L fluid required throughout. The kidney was carefully placed in the pelvis, the peritoneum was desufflated and the robot was undocked.

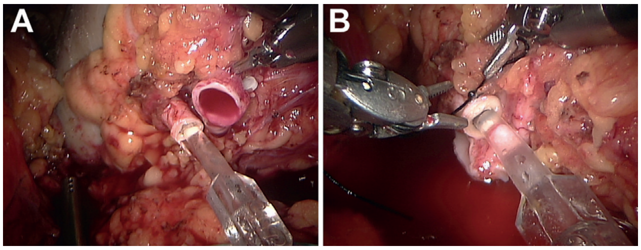

Figure 3. Intracorporeal cold perfusion of kidney using cannula and tubing passed through assistant port to allow renal artery perfusion until clear effluent was seen from renal vein (*A*). Note graft blanching. Cannula was secured to renal artery to allow for continuous intracorporeal hypothermic renal perfusion (*B*).

Step 3—Left external iliac vessel preparation. The bed was repositioned in the steep Trendelenburg position without patient repositioning. The robot was moved from over the left flank to between the legs. The bladder was dissected from the abdominal wall to enter the space of Retzius. The left EIA and EIV were circumferentially dissected with adequate length for clamping and anastomosis.

Step 4—Vascular anastomoses. The kidney was placed over the bladder with the perfusion catheter still in place. The EIV was clamped with laparoscopic bulldog clamps placed with robotic instruments and a venotomy incision was made. A running end-to-side anastomosis was created between the renal vein and the EIV using CV-6 Gore-Tex® suture (fig. 4, *A*). Hypothermic renal perfusion continued throughout. Before the last suture was placed the lumen was irrigated with heparinized saline through a 5Fr ureteral catheter to remove intraluminal

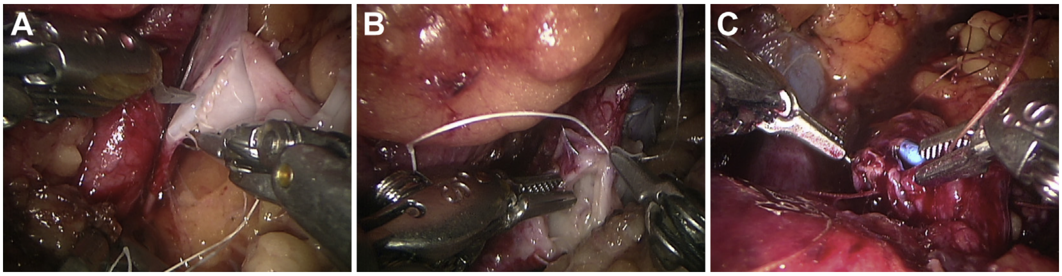

Figure 4. Intraoperative view of renal vein anastomosis to external iliac vein (*A*), renal artery anastomosis to external iliac artery (*B*) and ureteroureterostomy (*C*).

air. Upon completing the venous anastomosis a bulldog clamp was placed on the renal vein and the clamps were released from the EIV.

The perfusion cannula was removed from the renal artery. The end was trimmed to remove the portion that had been secured to the cannula with a tie. End-to-side arterial anastomosis was performed, similar to that of the vein (fig. 4, *B*).

Upon completion the clamps were removed beginning with the distal EIA, followed by the renal vein and then the proximal EIA. There was prompt return of uniform pink color to the kidney and urine was seen from the ureter within minutes. Laparoscopic Doppler ultrasound was performed to confirm flow.

Step 5—Left ureteroureterostomy. The distal ureter was dissected in the pelvis beyond the injury. The ureter was divided below the common iliac artery and brought into position for anastomosis to the renal end of the ureter. The proximal and distal ends were trimmed until bleeding was visualized. They were then spatulated. The proximal end of the stent was advanced through the renal end of the ureter into the kidney without requiring a wire. Tension-free ureteroureterostomy was performed over the stent in running fashion with 4-zero Vicryl® (fig. 4, *C*).

The kidney was pexed by securing capsular fat on the anterior kidney to the peritoneum with a robotic clip. All 3 anastomoses were examined (fig. 5). The robot was undocked. The fascia at the 12 mm port sites was closed and a drain was placed through an 8 mm port site.

Followup

Doppler ultrasound of the autotransplanted kidney was done on POD 1. SCr was evaluated on PODs 0 and 1, and 8 weeks and 5 months postoperatively. Mercaptoacetyltriglycine nuclear renogram was performed at 6 weeks, followed by ureteral stent removal. Intravenous and CT urograms were done 8 weeks and 5 months postoperatively, respectively.

RESULTS

Total operative time was 425 minutes with a surgeon console time of 334 minutes. Warm ischemia time (time from left renal artery ligation to intraarterial hypothermic renal perfusion) was 2.3 minutes. Cold ischemia time (time from initiation of hypothermic perfusion to termination of perfusion at the completion of the venous anastomosis) was 95.5 minutes.

Venous and arterial anastomosis time was 17.3 and 21.3 minutes, respectively. Rewarming time (time from termination of hypothermic renal perfusion to unclamping and reperfusion of the kidney) was 28.8 minutes. Ureteroureterostomy time was 26.6 minutes. Estimated blood loss was 50 ml.

The patient was treated postoperatively according to our routine common clinical pathway after robotic surgery as previously described.[24] Briefly, a clear liquid diet and ambulation were initiated within hours. Analgesia was provided with scheduled intravenous ketorolac and oral acetaminophen. Oxycodone (5 mg) -acetaminophen (325 mg) tablets were allowed but the patient required only 2 tablets during hospitalization and no intravenous narcotics. On POD 1 the Foley catheter was removed and a regular diet was given. The drain was removed after testing the creatinine level. Doppler ultrasound demonstrated excellent vascular flow with a normal renal resistive index of 0.63 to 0.68 (fig. 6, *A*). The patient was discharged home on POD 1 with standard instructions for post-robotic surgery convalescence.

Preoperative SCr was 1.00 mg/dl and SCr on POD 1 was 1.42 mg/dl. Eight weeks and 5 months postoperatively SCr was 0.81 and 0.95 mg/dl, respectively. Six weeks postoperatively mercaptoacetyltriglycine radionuclide angiogram revealed prompt good blood flow. A 20-minute renogram demonstrated good cortical uptake with a peak uptake time of 3 to 4 minutes, almost complete collecting system washout and no evidence of obstruction. The ureteral stent was removed in the office on the same day. Two weeks later (8 weeks postoperatively) intravenous urogram showed prompt contrast excretion at 5 minutes without extravasation (fig. 6, *B*). Five months postoperatively CT urogram revealed no ureteral obstruction and patent vascular anastomoses without stenosis (fig. 6, *C* to *F*).

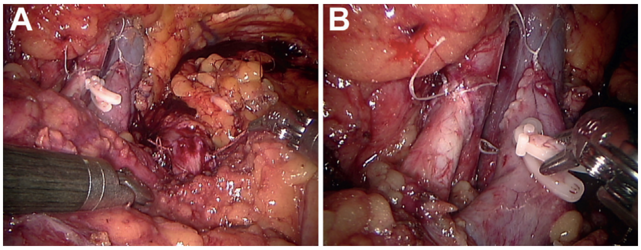

Figure 5. Intraoperative view of completed arterial, venous and ureteral anastomoses from left to right (*A*) and close-up of arterial (left) and venous (right) anastomoses (*B*).

DISCUSSION

A short segment of distal ureter can be repaired by ureteroureterostomy, a psoas hitch, a Boari flap or transureteroureterostomy. However, complex ureteral injuries with significant ureteral loss may necessitate bowel interposition or renal autotransplantation to salvage the kidney.[25]

Bowel interposition carries significant morbidity and is contraindicated in patients with renal insufficiency.[26,27] Bowel use also adds the risks of bowel obstruction, metabolic abnormalities, stone formation and obstruction from mucus.[27] The resulting chronic bacteriuria has been associated with renal deterioration in 25% to 34% of cases.[26] RATx avoids these complications and preserves

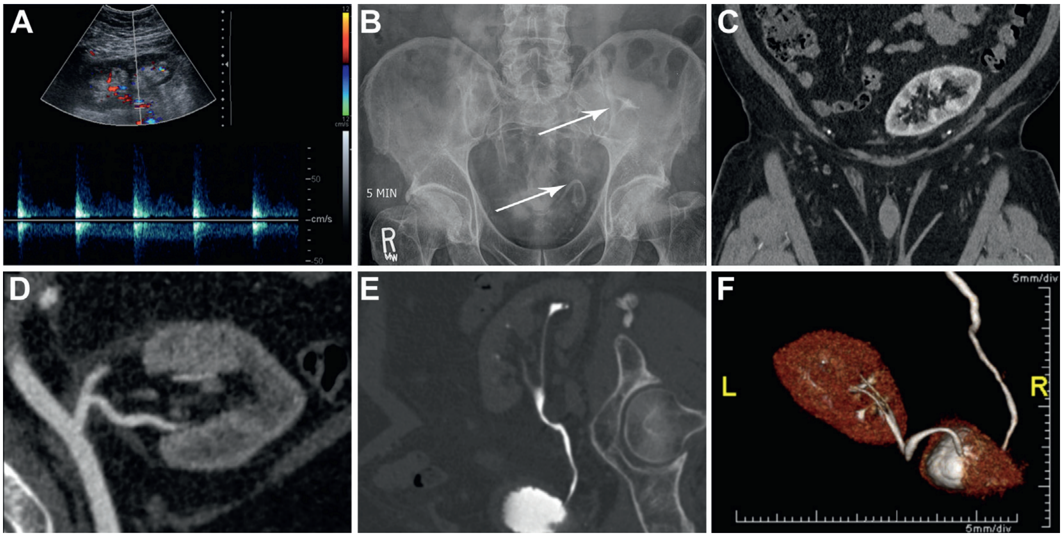

Figure 6. Postoperative imaging confirmed autotransplantation success, including Doppler ultrasound of autotransplanted kidney on POD 1 (*A*), prompt contrast excretion at 5 minutes on intravenous urogram 8 weeks postoperatively (*B*), healthy graft in pelvis on CT urogram 5 months postoperatively (*C*), patent arterial anastomosis (*D*), excretion phase without ureteral obstruction (*E*) and 3-dimensional reconstruction of autotransplanted kidney and ureter (*F*).

renal function, which is an important consideration particularly in patients with chronic kidney disease, a solitary kidney and/or nephrolithiasis.[6,25] In these cases RATx offers an alternative to nephrectomy with excellent outcomes demonstrated at select centers.[25,26] However, this procedure previously required open surgery with significant morbidity, which may be a disincentive in patients with a normal contralateral kidney.[8]

Laparoscopic renal harvest for autotransplantation provides an opportunity to decrease morbidity, although still with an open incision for the pelvic portion of the operation.[3,4] Laparoscopic nephrectomy with open autotransplantation was first described by Fabrizio et al.[5] Laparoscopic nephrectomy was performed with extraction through a periumbilical incision followed by transplantation through a Gibson incision.[5] Gill et al described retroperitoneoscopic laparoscopic nephrectomy followed by open autotransplantation in 4 patients in whom a Gibson incision was made for extraction and subsequent transplantation.[7] Meng et al reported the largest series of laparoscopic nephrectomies for autotransplantation in which Gibson incision extraction and transplantation were also performed with patient repositioning from the flank to the supine position.[6] Troxel et al used the planned extraction site incision for hand assisted laparoscopic nephrectomy.[9]

Bluebond-Langner et al performed laparoscopic nephrectomy and subsequent open autotransplantation in 4 patients.[2] They were the first to perform renal hypothermic perfusion intracorporeally before graft extraction. The concept of continuous cold perfusion of the renal artery to maintain cold ischemia is not new. It has been extensively used for storage of allograft kidneys with 1 study showing no difference in delayed graft function when used more than 24 hours.[28] Cold perfusion for ischemia has also been used during partial nephrectomy.[29] Finally, Meraney et al reported the feasibility of a completely

Figure 7. Immediate postoperative image shows patient after completely intracorporeal robotic renal autotransplantation.

intracorporeal laparoscopic renal autotransplantation in a porcine model with good graft function in 5 of 6 pigs.[30]

Our work represents the next step in the evolution of autotransplantation since we successfully performed the procedure in a completely intracorporeal fashion in a human. Since the kidney was never extracted, the typical 6 to 8 cm incision was avoided and the largest incision was only 12 mm (fig. 7). We think that this contributed to excellent convalescence with immediate ambulation, no intravenous narcotics and discharge home on POD 1.

While we believe that robotics facilitated the operation and helped achieve the precision needed, this initial experience demonstrates feasibility with room for improvement. Although vascular anastomosis times were reasonable, the cold ischemia and total operative times reflect the need to improve efficiency. As with any new procedure, a focus on safety and a favorable outcome are most important while efficiency will develop with time and the experience of multiple surgeons.

The technical challenges of the operation should not be taken lightly. Surgeons who consider this operation should have extensive experience with robotic surgery and ideally renal transplantation as well, especially if transplant surgeons will not be involved. Also, care should be taken with case selection since in our patient obesity created additional challenges. Unfortunately, because the number of patients with conditions that might be managed by RATx is small, there are even fewer ideal candidates, an issue that will justifiably hamper adoption.

We hope that the technical lessons that we learned will help those who embark on this procedure. We share our technique as a starting point. However, as with most novel procedures, it is certain to evolve and improve with further experience.

CONCLUSIONS

Although technically challenging, completely intracorporeal robot-assisted nephrectomy with RATx is a feasible approach to renal preservation after major ureteral injury. This operation may be considered in select patients in the hands of experienced robotic surgeons. However, further refinement is required as this novel procedure is cautiously reproduced and adopted by others.

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EDITORIAL COMMENT

Renal autotransplantation has remained underused due to the need for 2 major interventions (donor nephrectomy and transplantation) and perhaps to a lack of training in transplantation for many urologists. Robotic technique as described or with some modifications has potential in patients with complex ureteral loss.

Is it necessary or always possible to perfuse the kidney in situ in the peritoneal cavity? Also, arterial anomalies (multiple arteries, arterial plaques and intimal flaps) may require some vascular back table work to enable successful autotransplantation. While using an umbilical GelPort® may not appeal to intracorporeal purists, we have used this strategy during robotic transplant surgery to remove the kidney graft from the abdomen temporarily to prepare it on the bench in the comfort of ice slush before reintroduction.[1] It may also save precious operative time since redocking and iliac vascular bed preparation may be done while the kidney is prepared on the back table.

The authors chose to place the kidney in the left iliac fossa to perform ureteroureterostomy. The right iliac fossa is usually the preferred location due to its superficially located iliac vessels. Previous interventions with its attendant urinoma and adhesions, too, may dictate the use of the contralateral iliac fossa for transplantation. Distal ureteral loss, commonly associated with such complex ureteral injuries, would necessitate ureterovesicostomy with or without a psoas hitch.

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REPLY BY AUTHORS

As the first procedure of its kind, our technique of robotic autotransplantation will likely evolve. Input from expert robotic and transplant surgeons such as this and contributions from those who embark on robotic renal autotransplantation in the future will certainly lead to improvements in the procedure. We share enthusiasm for the GelPort to introduce harvested kidneys for robotic allogeneic transplantation. In contrast to requiring an incision to introduce a donor kidney through a GelPort, the difference in robotic autotransplantation is the benefit of never having to extract the kidney being autotransplanted. This allows the largest incision to be only 12 mm, which is the size of the port for the robotic scope. While removal of an autotransplant kidney and replacement into the abdomen through a GelPort could be explored if ever needed for complex vascular reconstructions, this would require a larger incision and the associated morbidity. With only 1 robotic autotransplantation performed to date, it is impossible to determine the best technique but intracorporeal cooling avoids this larger incision without compromising the goals of the operation.