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Research Article

Open Kidney Transplantation Using Living Donor Kidneys Procured with Robotic Assistance

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Abstract

Background: Robotic-Assisted Living Donor Nephrectomy (RALDN) has been shown to be a safe and feasible option, offering enhanced visualization and improved surgical dexterity, allowing for a potential increase in the living donor pool to perform pediatric and adult kidney transplants, even in cases of grafts with anatomical variants. We report our recent experience in using RALDN for Open Kidney Transplantation (OKT).

Materials and Methods: Between August 2021 and December 2024, 112 kidney transplant recipients underwent OKT using RALDN grafts obtained at our institution. Evaluated clinical outcomes during the first 12mo post-transplant included the incidence of Delayed Graft Function (DGF), surgical complications, estimated Glomerular Filtration Rate (eGFR), and graft loss.

Results: There were 14 pediatric and 98 adult recipients. Median recipient and donor ages were 41.9yr and 39.0yr, respectively. Male recipients comprised 63.4% (71/112); female donors comprised 56.2% (63/112). Among donors, no conversion to open surgery was required, and no post-operative complications attributed to the RALDN procedure were observed. Twenty-eight kidney grafts required back-table reconstruction. Median cold and warm ischemia times were 54.5min and 26.0min, respectively. One case (0.8%) of DGF was observed. While there were no recipient post-operative vascular complications, 3.6% (4/112) developed a urologic complication. Mean eGFR at 1mo, 3mo, 6mo, and 12mo post-transplant was 74.4, 77.1, 75.4, and 73.6 ml/min/1.73m^2, respectively. While no graft failures during the first 12mo post-transplant were observed, one patient died with a functioning graft.

Conclusion: RALDN is a safe and effective technique that provides favorable outcomes among both donors and recipients; this minimally invasive approach should be offered as a safe alternative to living donor patients.

Keywords: Clinical Results; Open Kidney Transplantation; Robotic-Assisted Living Donor Nephrectomy

Introduction

Living kidney donation is the best approach to increase the number of kidney transplants, reduce waiting times, and increase the recipient's life expectancy by reducing the retransplant rate [1]. To increase living kidney donation and to decrease post-operative pain and morbidity that is associated with open donor nephrectomy, minimally invasive surgery was introduced into the field of living kidney donation. First, Laparoscopic Donor Nephrectomy (LDN) [2] and more recently, robotic-assisted laparoscopic donor nephrectomy (RALDN) [3], both provide a less invasive surgical approach as compared with open donor nephrectomy. RALDN is gaining popularity in the field of living kidney donation [3] and is associated with smaller incisions, shorter hospital stays, and lower risk ratios for the development of surgical site infections and symptomatic lymphoceles [3-4]. We wanted to evaluate the feasibility, safety, and clinical outcomes in using RALDN at our transplant center, including short and longer-term outcomes of kidney transplants performed using our surgical modifications of the conventional kidney transplant technique [5-7]. Results among 112 RALDN transplant recipients performed at our center since 2021 are reported here.

Materials and Methods

Patient Selection and Study Design

Between August 26, 2021 and December 12, 2024, 14 pediatric and 98 adult recipients of a kidney-alone transplant were performed consecutively at our center, using living donor kidneys obtained via RALDN and transplanted using a modified kidney transplant surgical technique [5-7]. This study was approved by the University of Miami Institutional Review Board and adheres to the ethical principles of the Helsinki Declaration, as revised in 2013. Transplant surgeons, pediatric and adult transplant nephrologists, and a multidisciplinary kidney transplant team that included anesthesiologists, social workers, pharmacists, nutritionists, pre-transplant donor and recipient coordinators, donor advocates and finance counselors assessed both donors and (pediatric and adult) recipients. Each set of patients (donor and recipient) underwent an extensive laboratory workup, including comprehensive metabolic panel, electrolytes, serology, and complete blood count. Chest X-ray, abdominal ultrasound echocardiogram, and electrocardiogram were also completed. The donor had computed tomography angiography with intravenous contrast to assess kidney anatomy, vascular and collection systems plus any other kidney pathology. Living donor candidates were above 18 years of age, and regarding the data acquired for living donors, we compiled donor age, sex, race/ethnicity, height, weight, Body Mass Index (BMI), blood work, urinalysis, donor kidney biopsy, donor kidney size and renal vessel length. If the utilized living donor kidney had anatomic variants, back table vascular reconstruction was performed. Recipient demographics included age, sex, race/ethnicity, cause of end stage renal disease, and calculated Panel Reactive Antibody (cPRA). All urologic, vascular, and other surgical complications were recorded. Urologic complications included ureteral leak, ureteral stricture, Ureteropelvic Junction (UPJ) obstruction, Vesicoureteral Reflux (VUR), and urinoma. Vascular complications included renal artery thrombosis, renal vein thrombosis, and renal artery stenosis. Other surgical complications included lymphocele development, wound complication (infection, dehiscence, or seroma), and development of a peri-renal hematoma or peri-renal collection. Suspected urologic complications were evaluated with renal ultrasonography, mercaptoacetyltriglycine scan, and/or antegrade nephrostogram. Urologic complications were treated by either percutaneous radiological procedures, surgery, or a combination of both. Suspected ureteral stenosis/stricture was evaluated along with serial monitoring for BK virus replication (in blood). Voiding cystourethrogram was not routinely performed, as routine evaluation for vesicoureteral reflux was not considered to be necessary in our transplant recipients; therefore, only symptomatic reflux was evaluated and considered as a urologic complication. Suspected vascular and/or other surgical complications were first evaluated by renal ultrasonography and, if necessary, by computerized tomography scan or magnetic resonance angiography. Surgical vs. conservative treatment was determined according to test results and complication severity.

Immunosuppression

All recipients received standard induction immunosuppression intraoperatively and during the first week post-transplant with Antithymocyte Globulin (rATG) (1 mg/kg IV for 3 doses in most cases) and methylprednisolone (500 mg IV daily for 3 doses), followed by a tapering regimen to a maintenance dose for prednisone of 5 mg PO daily, coinciding with the achievement of therapeutic tacrolimus levels (target trough: 6–8 ng/mL). Once therapeutic tacrolimus levels were achieved, the plan was to discontinue the use of daily low-dose corticosteroids (i.e., corticosteroid avoidance). Of note, some patients received dual induction therapy with rATG and basiliximab (an older protocol). In addition, patients considered to be highly sensitized (with high cPRA or preformed donor specific antibodies) also received one dose of rituximab as part of induction therapy. Maintenance immunosuppression consisted of a calcineurin inhibitor (tacrolimus) and an antiproliferative agent (mycophenolate acid). Oral tacrolimus was initiated on post-operative day 2 (in patients with immediate graft function), with dosing adjusted based on therapeutic drug monitoring and renal function. Mycophenolate acid (720 mg twice daily) was also introduced on post-operative day 2, with adjustments made according to white

blood cell count and gastrointestinal tolerance [8].

The Surgical Procedure

Living donor allografts were obtained via a RALDN. In performing a left RALDN, the patient was positioned in a modified lateral decubitus position on the right side to optimize left renal exposure. Adequate padding was applied to protect pressure points and prevent development of pressure neuropathies, and the operating table was flexed at the kidney level. Sterility was maintained by preparing and draping the abdomen followed by a procedural timeout to confirm patient identity, procedural details, and ABO compatibility. Pneumoperitoneum was established using Palmer's technique with a Veress needle in the left upper quadrant, while careful monitoring maintained optimal intra-abdominal pressure. Under direct vision, robotic ports were inserted: an 8mm left subcostal port utilizing OptiView technology for a 5mm laparoscopic camera, an 8mm left periumbilical port, a 12mm left paramedian port, an 8mm suprapubic paramedian port placed through a Pfannenstiel incision, and a 12mm assistant port in the midline (Figure 1A). The robotic arms were configured with fenestrated bipolar forceps through the subcostal port, a high-definition camera through the periumbilical port, monopolar curved scissors through the paramedian port - later switched to a vessel sealer, and ProGrasp forceps through the suprapubic port. The procedure began with an abdominal inspection to assess for any pathology. The left colon was mobilized, and the splenorenal ligament was dissected to expose the kidney, with the renal vein, left gonadal vein, and adrenal gland identified, dissected, and ligated using clips. The ureter was dissected to the left common iliac artery, and the kidney was mobilized for better renal hilum access. The kidney was liberated, renal artery and vein isolated, and lumbar veins managed. The kidney was then prepared for extraction by clipping and cutting the ureter, followed by stapling of the renal artery and vein. The kidney was placed in a retrieval bag, extracted through the Pfannenstiel incision. The rectus muscle was sutured with continuous PDS, and fibrin glue was applied for hemostasis. The procedure was concluded with the robotic system undocking and closure of skin incisions.

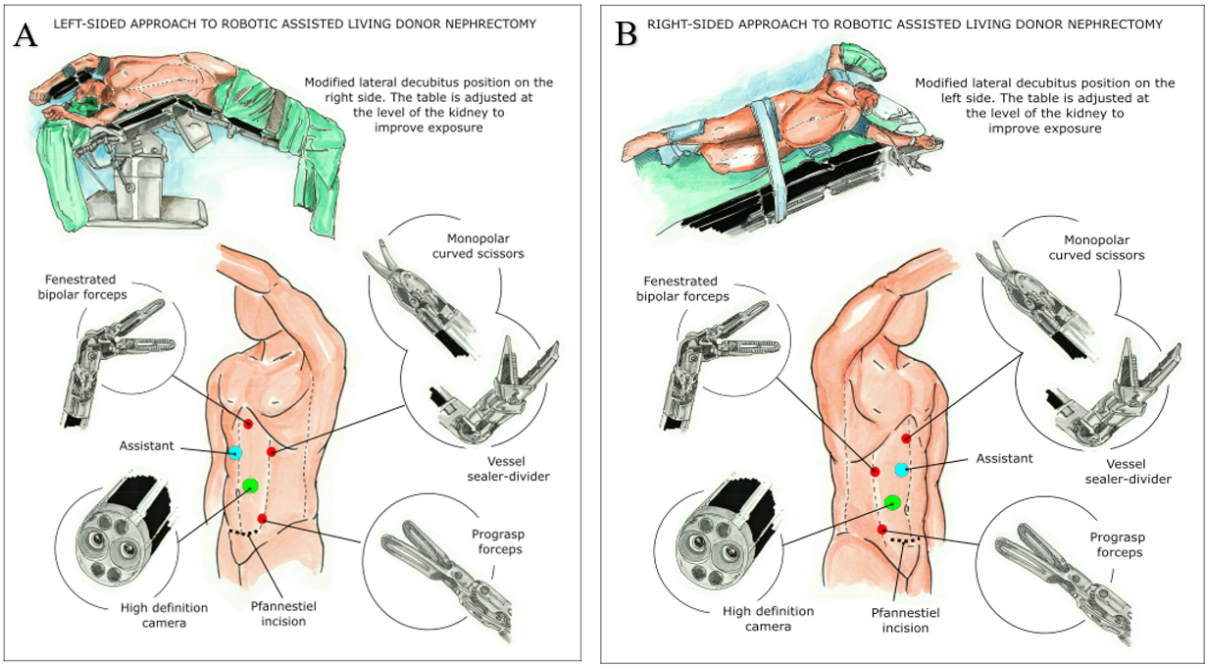

Figure 1: A) Port placement for robotic-assisted left donor nephrectomy. B) Port placement for robotic-assisted right donor nephrectomy.

In performing a right RALDN, the patient was placed in a modified lateral decubitus position on the left side, and the operating table was adjusted at the level of the kidney to improve renal exposure, with special attention being given to padding to prevent development of pressure neuropathies. Aseptic technique was adhered to in preparing and draping the abdomen, followed by a surgical timeout to confirm patient identity, procedural specifics, and ABO compatibility. Pneumoperitoneum was established using Palmer's technique, inserting a Veress needle into the right upper quadrant. Robotic ports were placed under direct vision along the midclavicular line. An 8mm right subcostal port was placed using OptiView technology, which initially housed a 5mm laparoscopic camera. Additionally, an 8mm right periumbilical port, a 12mm right paramedian port, an 8mm suprapubic paramedian port via a Pfannenstiel incision, a 12mm assistant port between the initial ports along the midline, and a 5mm port at the xiphisternum for liver retraction were positioned (Figure 1B). With the system docked, ProGrasp forceps were used through the suprapubic port for tissue manipulation. Fenestrated bipolar forceps were inserted through the right paramedian port for delicate tissue manipulation. A high-definition laparoscopic camera provided visual guidance through the right periumbilical port, and monopolar curved scissors, later exchanged for a vessel sealer, were used through the right subcostal port for cutting and dissection. A comprehensive intra-abdominal inspection ruled out any malignancies. The right colon was mobilized medially, and the hepato-renal ligament was divided to release the upper kidney pole. For liver retraction, a laparoscopic grasper was employed. The renal vein and right gonadal vein were carefully dissected, and the ureter was isolated to the level of the right common iliac artery. Using the fourth robotic arm for elevation, access to the renal hilum was gained. The gonadal vein and right adrenal gland were dissected from their respective structures.

The kidney was liberated after dissecting Gerota's fascia posteriorly. The renal artery and vein were exposed and sometimes clamped with a metal Bulldog clamp. The ureter was distally clipped and cut proximally to the clip. While the kidney was elevated using arms 1 and 4, the SureForm 45 instrument stapler from arm 3 was employed to secure the artery and vein. For kidney retrieval, the organ was placed in a Laparoscopic Specimen Retrieval System bag, which was introduced and removed through the Pfannenstiel incision. The rectus muscle was sutured with a continuous PDS suture, and fibrin glue was applied for hemostasis. To complete the procedure, the robotic system was undocked and skin incisions closed. No surgical drainage system was used in any part of the donor surgery. For pediatric and adult recipient operations, to access the retroperitoneal space, a modified (pediatric) or regular (adult) Gibson incision was executed in the right lower quadrant. To expose the right iliac vessels, the peritoneum was moved medially, and blunt dissection was carried out posteriorly to the right renal fossa. Exposition was supported by a Bookwalter retractor. The robotic-assisted procured graft was arranged on the back-table. The perinephric fat was resected up to the lower pole. Renal artery(s) and renal vein(s) were visualized and dissected, and their lengths were measured. Location and minimal dissection of the ureter was accomplished. Any identified anatomic variants were reconstructed as described below. The allograft was subsequently approached to the surgical area. First, an anastomosis with running 6-0 polypropylene sutures was completed between the donor´s renal vein and the recipient´s Inferior Vena Cava (IVC) (pediatric recipients) (Figure 2) or external iliac vein (adult recipients). Then, 7-0 polypropylene sutures were utilized to anastomose the donor´s renal artery to the recipient´s right common iliac artery (pediatric recipients) or external iliac artery (adult recipients) [5-7]. The ureteroneocystostomy was performed following our extravesical ureteroneocystostomy surgical technique without ureteral stent placement [7]. Jackson-Pratt drains were also not used at the time of transplant [5-7].

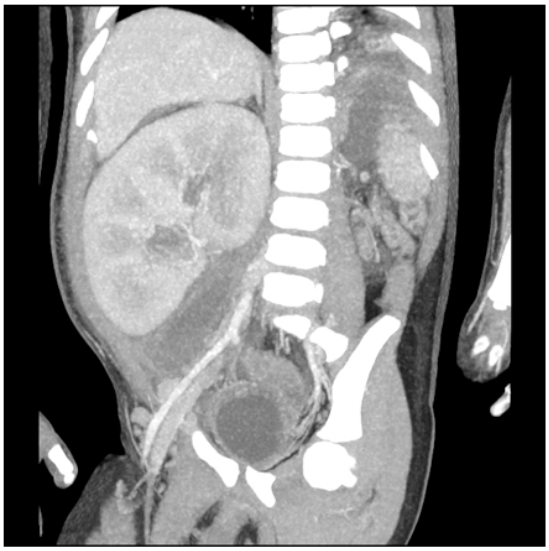

Figure 2: Computed tomography scan imaging of a two-year old recipient with an adult kidney allograft removed robotically occupying about half of the abdominal cavity.

Donor Vascular Variations and Reconstruction

Among the 28 donor kidneys that required back-table reconstruction, 27 underwent vascular reconstruction (14 requiring conjoining of two renal arteries, 12 requiring deceased donor vascular graft extensions of renal arteries and/or renal veins, and 1 requiring both procedures), and 1 underwent urologic reconstruction (i.e., 2 ureters were anastomosed together). In addition, one donor kidney underwent a lower pole cyst removal.

Statistics

Frequency distributions were determined for baseline categorical variables as well as for clinical outcomes that were dichotomous in nature. Mean and Standard Error (SE) were calculated (along with median and range) for baseline continuous variables as well as for clinical outcomes that were represented as continuous variables. Of note, Estimated Glomerular Filtration Rate (eGFR) was calculated among children (<19 years of age at transplant) using the updated Schwartz formula; eGFR was calculated among adults using the conventional race-based CKD-EPI formula. In addition, the following clinical outcomes that occurred during the first 12 months post-transplant were determined: Delayed Graft Function (DGF), surgical complications (vascular, urologic, wound complication, lymphocele, peri-renal hematoma, and peri-renal collection), Biopsy-Proven Acute Rejection (BPAR), graft failure (return to permanent dialysis or retransplantation, whichever occurred first), Death with a Functioning Graft (DWFG), and eGFR at 1, 3, 6, and 12 months post-transplant. Other than performing t-tests of association for mean eGFR between children and adults, no other formal statistical tests were performed in this study, just descriptive statistics.

Results

Fourteen children and 98 adults received an open kidney transplant with a RALDN graft. Donor and recipient demographics are detailed in Table 1. Mean recipient age was 42.8 ± 1.8 years [median=41.9, range: 3.1-80.6 years]. Male recipients comprised 63.4% (71/112); 59.8% (67/112) were Hispanic, and 6.3% (7/112) were African-American. Mean recipient BMI was 25.2 ± 0.5 kg/m² [median=25.1, range: 14.9-38.4 kg/m²]. Among the 98 adult recipients, mean recipient age and BMI were 47.2 ± 1.6 years [median=46.1, range: 21.3-80.6 years] and 26.0 ± 0.4 kg/m² [median=26.1, range: 17.1-38.4 kg/m²], respectively, with 60.2% (59/98) being male, 62.2% (61/98) being Hispanic, and 7.1% (7/98) being African-American. Among the 14 pediatric recipients, mean recipient age and BMI were 11.8 ± 1.4 years [median=12.4, range: 3.1-18.9 years] and 19.8 ± 1.2 kg/m² [median=18.3, range: 14.9-31.4 kg/m²], respectively, with 85.7% (12/14) being male, 42.9% (6/14) being Hispanic, and 0.0% (0/14) being African-American. Mean donor age was 40.0 ± 1.1 years [median=39, range: 18-68 years], with 56.2% (63/112) of donors being female. Living related donors represented 58.9% (66/112); living unrelated donors represented 41.1% (46/112). Left donor kidneys were utilized in 88.4% (99/112) of cases; right donor kidneys were utilized in 11.6% (13/112) of cases. Reasons for using the right donor kidney included: having a smaller right donor kidney volume (N=11), having a functional UPJ obstruction of the right donor kidney (N=1), and having 2 simple cysts on the right donor kidney (N=1, with one measuring 1.5cm). The pre-implant biopsy showed a mean percentage of sclerotic glomeruli being 5.8 ± 0.8% [median=3.6, range: 0.0-59.5%]. Notably, no intraoperative complications of the living donor patients were recorded, and all RALDN surgical steps were successfully completed robotically.

Baseline Variable	Mean ± SE if continuous; Percentage with characteristic if categorical
Recipient Age (yr)	42.8 ± 1.8 (N=112)
	[Median=41.9, Range: 3.1-80.6]
Recipient Age (yr):	
<19	12.5% (14/112)
19-49	52.7% (59/112)
≥50	34.8% (39/112)
Recipient Gender:	
Female	36.6% (41/112)
Male	63.4% (71/112)
Recipient Race/Ethnicity	
Black (non-Hispanic)	6.3% (7/112)
Hispanic	59.8% (67/112)
White (non-Hispanic)	32.1% (36/112)
Asian	1.8% (2/112)
Recipient BMI (kg/m^2)	25.2 ± 0.5 (N=112)

	[Median=25.1, Range: 14.9-38.4]
Retransplant Status	
Primary	83.0% (93/112)
Retransplant	17.0% (19/112)
Preemptive Transplant	
No	67.0% (75/112)
Yes	33.0% (37/112)
Pretransplant Dialysis Type	
Hemodialysis	41.1% (46/112)
Peritoneal	21.4% (24/112)
Use of Both Modalities	4.5% (5/112)
Pretransplant Time on Dialysis (mo)	19.2 ± 2.8 (N=75)
	[Median=10.4, Range: 0.3-148.4]
Cause of ESRD	
ADPKD	7.1% (8/112)
DM	10.7% (12/112)
HTN Only	16.1% (18/112)
FSGS	13.4% (15/112)
IgA Nephropathy	9.8% (11/112)
Reflux Nephropathy	8.0% (9/112)
Congenital Disease	7.1% (8/112)
SLE Only	6.3% (7/112)
Granulomatosis with Polyangiitis	1.8% (2/112)
Other	19.6% (22/112)
Pretransplant Platelet Count (10^3/uL)	229.5 ± 7.1 (N=112)
	[Median=219.0, Range: 79.0-502.0]
Pretransplant Prothrombin Time (sec)	13.9 ± 0.2 (N=112)
	[Median=13.5, Range: 10.2-32.4]
Pretransplant INR	1.15 ± 0.08 (N=112)
	[Median=1.03, Range: 0.73-9.99]
Pretransplant Partial Thromboplastin	
Time (sec)	29.4 ± 0.3 (N=112)
	[Median=29.0, Range: 22.0-45.0]
Pretransplant Fibrinogen (mg/dL)	409.2 ± 11.4 (N=110)
	[Median=387.5, Range: 77.0-819.0]

Donor Type	
Living Related	58.9% (66/112)
Living Unrelated	41.1% (46/112)
Donor Age (yr)	40.0 ± 1.1 (N=112)
	[Median=39.0, Range: 18.0-68.0]
Donor Gender:	
Female	56.2% (63/112)
Male	43.8% (49/112)
Donor Race/Ethnicity	
Black (non-Hispanic)	7.1% (8/112)
Hispanic	61.6% (69/112)
White (non-Hispanic)	29.5% (33/112)
Asian	1.8% (2/112)
Donor Kidney	
Left	88.4% (99/112)
Right[1]	11.6% (13/112)
Vascular/Other Reconstructions (Performed on the Back Table)	
None	75.0% (84/112)
2 RAs Anastomosed Together	12.5% (14/112)
2 RAs Anastomosed Together, and 2	
RVs Reconstructed with DD Veins	0.9% (1/112)
RV (or RVs) Reconstructed with DD Vein(s)	8.9% (10/112)
Both RA & RV (or RVs) Reconstructed with DD Veins	1.8% (2/112)
2 Ureters Anastomosed Together	0.9% (1/112)
Donor Major Renal Artery Length (cm)	3.34 ± 0.07 (N=112)
	[Median=3.45, Range: 1.0-5.5]
Donor Major Renal Vein Length (cm)	3.98 ± 0.11 (N=112)
	[Median=4.00, Range: 1.0-6.5]
CIT (min)	74.2 ± 13.3 (N=112)
	[Median=54.5, Range: 30.0-1528.0]
WIT (min)	26.7 ± 0.4 (N=112)
	[Median=26.0, Range: 18.0-41.0]
EBL (cc)	49.6 ± 8.7 (N=112)
	[Median=20.0, Range: 5.0-800.0]

Donor Percent Sclerotic Glomeruli (Pretransplant Biopsy)	5.8 ± 0.8 (N=111)
	[Median=3.6, Range: 0.0-59.5]
Donor Arteriolosclerosis (Pretransplant Biopsy)	
None	42.3% (47/111)
Minimal-to-Mild	56.8% (63/111)
Moderate	0.9% (1/111)
Number of rATG Induction Doses	
1	23.2% (26/112)
2	6.3% (7/112)
3	70.5% (79/112)
Number of Basiliximab Induction Doses	
0	55.4% (62/112)
1	9.8% (11/112)
2	34.8% (39/112)
Rituximab Dose Given with Induction	
No	73.2% (82/112)
Yes	26.8% (30/112)

[1]Reasons for using the right donor kidney included: having a smaller right donor kidney volume (N=11), having a functional UPJ obstruction of the right donor kidney (N=1), and having 2 simple cysts on the right donor kidney (N=1, with one cyst measuring 1.5cm).

Table 1: Distributions of Selected Baseline Variables (N=112).

In addition, no surgical drainage nor stent placement was used in recipients at the time of transplant. Median primary renal artery length was 3.5cm [range: 1.0-5.5cm]; median primary renal vein length was 4.0cm [range: 1.0-6.5cm]. Anatomic kidney variants were encountered in 28 cases as described in detail in the Materials and Methods section. Of these cases, 15 grafts had multiple renal vessels. The external iliac vein and artery were utilized for end-to-side vascular anastomosis in adult recipients, whereas IVC and common iliac artery were used for end-to-side vascular anastomosis in pediatric recipients. There were 13 right donor kidneys procured robotically, and in 11 of these cases, the right kidney had a smaller volume compared with the left kidney (results not shown). One right donor kidney had 2 cysts, and the last presented with a functional UPJ obstruction. Characteristics of the robotically procured kidney allografts are also described in Table 1. Mean CIT was 74.2 ± 13.3 minutes [median=54.5, range: 30-1528 minutes], and mean WIT was 26.7 ± 0.4 minutes [median=26, range: 18-41 minutes]. Mean EBL was 49.6 ± 8.7 cc [median=20, range: 5-800 cc]. Clinical outcomes, including surgical complications and renal function, are described in Table 2. One patient (0.9%, 1/112) developed DGF. During the first 12 months post-transplant, the observed percentages of patients who developed a urologic complication, vascular complication, wound complication, symptomatic lymphocele, peri-renal hematoma, and peri-renal collection were 3.6% (4/112), 0.0% (0/112), 0.9% (1/112), 0.0% (0/112), 2.7% (3/112), and 25.0% (28/112), respectively. Among the 4 patients who developed a urologic complication, the following details were observed: i) one patient developed necrosis of the ureter (with a ureteral leak) at 0.6 months post-transplant, which was treated with debridement of necrotic tissue, ureteral reimplantation, and stent placement, ii) one patient developed a ureteral stricture at 2.3 months post-transplant, which was treated with nephroureteral catheter placement and balloon plasty, iii) one patient developed UPJ obstruction (and hydronephrosis) at 3.9 months post-transplant, which was treated with balloon plasty, double J stent placement, and finally by robotic pyeloureterostomy (of note, this patient had received the right donor kidney having a functional UPJ obstruction, as mentioned above), and iv) one patient developed a grade IV VUR (and hydronephrosis) at 5.1 months post-transplant, which was treated with Deflux injection into the ureter and ureteral stent placement.

Outcome Variable	Mean ± SE if continuous; Percentage with characteristic if categorical
Developed DGF:	
No	99.1% (111/112)
Yes	0.9% (1/112)
Recipient Length of Hospital Stay (Days)	5.4 ± 0.4 (N=112)
	[Median=4, Range: 2-31
Donor Length of Hospital Stay (Days)	1.3 ± 0.1 (N=112)
	[Median=1, Range: 1-4]
Developed a Urologic Complication during the First 12mo Post-transplant	
No	96.4% (108/112)
Yes[1]	3.6% (4/112)
Developed a Vascular Complication during the First 12mo Post-transplant	
No	100.0% (112/112)
Yes	0.0% (0/112)
Developed a Wound Complication during the First 12mo Post-transplant	
No	99.1% (111/112)
Yes[2]	0.9% (1/112)
Developed a Symptomatic Lymphocele during the First 12mo Post-transplant	
No	100.0% (112/112)
Yes	0.0% (0/112)
Developed a Hematoma during the First 12mo Post-transplant	
No	97.3% (109/112)
Yes[3]	2.7% (3/112)
Developed a Peri-Renal Collection during the First 12mo Post-transplant	
No	75.0% (84/112)
Yes[4]	25.0% (28/112)
Developed Any Surgical Complication during the First 12mo Post-transplant	
No	70.5% (79/112)
Yes[5]	29.5% (33/112)
Developed Biopsy-Proven Acute Rejection during the First 12mo Post-transplant	
No	93.7% (105/112)
Yes[6]	6.3% (7/112)
Developed (Death Censored) Graft Failure during the First 12mo Post-transplant	

No	100.0% (112/112)
Yes[7]	0.0% (0/112)
Death with a Functioning Graft during the First 12mo Post-transplant	
No	99.1% (111/112)
Yes[7]	0.9% (1/112)
Developed (Death Uncensored) Graft Loss during the First 12mo Post-transplant	
No	99.9% (111/112)
Yes[7]	0.9% (1/112)
eGFR at 1mo post-tx (ml/min/1.73m^2)[8]	74.4 ± 2.2 (N=112)
	[Median=71.6, Range: 26.6-155.8]
eGFR at 3mo post-tx (ml/min/1.73m^2)[8]	77.1 ± 2.0 (N=111)
	[Median=77.2, Range: 30.9-129.6]
eGFR at 6mo post-tx (ml/min/1.73m^2)[8]	75.4 ± 1.9 (N=101)
	[Median=75.4, Range: 26.3-122.9]
eGFR at 12mo post-tx (ml/min/1.73m^2)[8]	73.6 ± 2.0 (N=84)
	[Median=71.9, Range: 21.7-111.0]

[1]Among the 4 patients who developed a urological complication during the first 12 months post-transplant, the following details were observed: i) one patient developed necrosis of the ureter (with a ureteral leak) at 0.6mo post-transplant, which was treated with debridement of necrotic tissue, ureteral reimplantation, and stent placement, ii) one patient developed a ureteral stricture at 2.3mo post-transplant, which was treated with nephroureteral catheter placement and balloon plasty, iii) one patient developed UPJ obstruction (and hydronephrosis) at 3.9mo post-transplant, which was first treated with balloon plasty and stent placement, followed by robotic pyeloureterostomy, and iv) one patient developed grade IV vesicoureteral reflux (and hydronephrosis) at 5.1mo post-transplant, which was treated with Deflux injection into the ureter and ureteral stent placement.

[2]This patient developed wound dehiscence at 1.2mo post-transplant.

[3]Three patients developed a hematoma at day 0 (the first day) post-transplant; an evacuation was performed in one case in which the hematoma was due to coagulopathy.

[4]The median time-to-development of a perirenal collection was day 2 (range: day 0-1.8mo) post-transplant.

[5]A total of 4 patients developed a 2nd surgical complication during the first 12mo post-transplant: i) one patient developed a peri-renal collection at 0.39mo post-transplant subsequent to developing a hematoma at day 0 post-transplant, ii) one patient developed necrosis of the ureter (with a ureteral leak) at 0.62mo post-transplant following the development of a peri-renal collection at 0.56 post-transplant, iii) one patient developed a 2nd peri-renal collection at 1.4mo post-transplant following a 1st peri-renal collection that developed at 0.33mo post-transplant; and iv) one patient developed a ureteral stricture at 2.3mo post-transplant following the development of a peri-renal collection at day 0 post-transplant.

[6]Grades of first BPAR for these 7 episodes included: Borderline (N=4), IA (N=2), and IIA (N=1); 3/7 cases received antilymphocyte treatment for the rejection episode (Borderline with microvascular involvement in 1 case, IA in 1 case, and IIA in 1 case). Median time-to-first BPAR for these 7 cases was 5.8 (range: 1.8-11.9) months post-transplant.

[7]The 112 study participants were transplanted between 8/26/21 and 12/12/24; date of last follow-up for this study was April 1, 2025. As of the last follow-up date, one patient (1/112) has experienced graft loss during the first 12mo post-transplant (a death with a functioning

graft due to sepsis at 1.0mo post-transplant). Median follow-up among the 111 patients who were alive with a functioning graft at either 12mo post-transplant or last follow-up, was 12mo post-transplant. Among these 111 patients, 76.6% (85/111) have been followed through 12mo post-transplant.

[8]Among the 14 children (<19 years of age at transplant), the updated Schwartz formula was used in calculating eGFR. Among the 98 adults, the conventional race-based CKD-EPI formula was used in calculating eGFR.

Table 2: Distributions of Selected Outcomes Variables (N=112).

The patient with a wound complication had developed wound dehiscence at 1.2 months post-transplant. Additionally, 3 patients developed a hematoma at day 0 (the first day) post-transplant; an evacuation was performed in one case in which the hematoma was due to coagulopathy. Median time-to-developing a perirenal collection for the 28 patients who developed one or more peri-renal collections was day 2 (range: day 0-1.8 months) post-transplant. Table 2 also shows that 29.5% (33/112) of patients developed one or more surgical complications during the first 12 months post-transplant. In total, there were 4 patients who developed a 2nd surgical complication during the first 12 months post-transplant: i) one patient developed a peri-renal collection at 0.39 months post-transplant after developing a hematoma at day 0 post-transplant, ii) one patient developed necrosis of the ureter (with a ureteral leak) at 0.62 months post-transplant following the development of a peri-renal collection at 0.56 post-transplant, iii) one patient developed a 2nd peri-renal collection at 1.4 months post-transplant following a 1st peri-renal collection that developed at 0.33 months post-transplant; and iv) one patient developed a ureteral stricture at 2.3 months post-transplant following the development of a peri-renal collection at day 0 post-transplant. The observed percentage of patients who developed a first BPAR during the first 12 months post-transplant was 6.3% (7/112). Grades of first BPAR for these 7 episodes included: Borderline (N=4), IA (N=2), and IIA (N=1); 3/7 cases received antilymphocyte treatment for the rejection episode (Borderline with microvascular involvement in 1 case, IA in 1 case, and IIA in 1 case). Median time-to-first BPAR for these 7 cases was 5.8 (range: 1.8-11.9) months post-transplant. Mean eGFR at 1, 3, 6, and 12 months was 74.4 ± 2.2 mL/min/1.73 m² (N=112) [median=71.6; range: 26.6-155.8], 77.1 ± 2.0 mL/min/1.73 m² (N=111) [median=77.2; range: 30.9-129.6], 75.4 ± 1.9 mL/min/1.73 m² (N=101) [median=75.4; range: 26.3-122.9], and 73.6 ± 2.0 mL/min/1.73 m² (N=84) [median=71.9; range: 21.7-111.0]. During the first 12 months post-transplant no patients developed graft failure; however, one patient experienced DWFG (due to sepsis) at 1.0 months post-transplant. As of the last follow-up date, April 1, 2025, 76.6% (85/111) of patients who were alive with a functioning graft had been followed for at least 12 months post-transplant. Finally, it should be noted that median donor length of hospital stay (LOS) was 1 day (range: 1–4 days); median recipient LOS was 4 days (range: 2–31 days). Among the donors, there were no conversions of RALDN to open surgery, and no post-operative complications attributed to the RALDN procedure were observed. Post-operative recovery went smoothly for each of the living donors.

Discussion

Kidney transplantation should be the first option of treatment for pediatric and adult patients with End-Stage Kidney Disease (ESKD), as survival rates augment substantially more favorably when compared to being on dialysis [9-11]. Advancements in immunosuppressive regimens, antimicrobial agents, and novel surgical techniques have improved kidney transplant results [5-7,12,13]. Nevertheless, while the number of pediatric and adult patients with ESKD on the transplant waitlist in the U.S. rose in 2023 to 2,956 and 141,886, respectively, only 791 and 27,351 received a kidney transplant in that same year, respectively [10]. Additionally, Living Donor Kidney Transplantation (LDKT) remains concernedly low, accounting for only 30.5% and 22.1% of the total kidney transplants performed in the pediatric and adult kidney transplant population in 2023 [10]. We presented in this series a detailed experience of using robotically procured living donor kidney grafts for transplantation in pediatric and adult patients at a single transplant center. Out of the 112 cases, 28 involved grafts with variations in vascular or renal anatomy that required bench-work reconstruction prior to implantation into the recipient. While back table reconstruction would also have been necessary if these living donor kidneys had been procured laparoscopically, since August 2021, we began using the robot for living donor nephrectomy replacing laparoscopic donor nephrectomy. We believe that this report has now demonstrated our main goal of showing robotically procured kidneys can safely be used for transplantation in ESKD recipients. This report demonstrates that the use of the robot in procuring living donor kidneys (including those with complex vascular anatomy) for pediatric and adult kidney recipients can achieve favorable results. RALDN has shown numerous benefits including increased surgical precision due to enhanced visualization and improved surgical dexterity when using the robotic arms to preserve sufficient vascular length, which is essential in cases of donor kidneys with complex anatomy [3,14,15], particularly when transplanted into pediatric recipients. Clearly, robotic-assisted donor nephrectomy has camera stability

and excellent optical 3-dimensional magnification that can be advantageous in cases of multiple renal vessels [3].

RALDN has also been reported to reduce donor pain post-nephrectomy [14]. Our study is the first analysis of living donor kidneys that were procured using RALDN and open kidney transplants that involved modifications of the conventional kidney transplant technique for pediatric and adult recipients, including elimination of the need for performing surgical drainage and ureteral stenting at the time of transplant [5-7]. Surgical complications continue to be a major concern in the field of kidney transplantation. Therefore, adopting minimally invasive techniques such as RALDN for donor kidney procurement may improve outcomes for both donors and recipients. In our study, the combination of RALDN and the modified open kidney transplant technique was associated with a low rate of surgical complications, supporting their potential as safe and effective options for broader adoption in the kidney transplant field. Of note, our donor patients will be followed for at least 24 months post-donation, respectively, according to OPTN policy [16]. Pelegrin et al reported a similar study of a large series of 118 RALDN and kidney transplant recipients analyzing peri- and postoperative complications - short, medium and long-term outcomes were favorable and very compatible with our results [17]. Their RALDNs were performed entirely robotic-assisted without any manual assistance, and they utilized either Hem-O-Lock or the robotic Hem-O-clipper for controlling the renal pedicle. In our series, we opted for the robotic robot-controlled surgical stapler, as the use of Hem-O-Lock is currently banned in the United States for living donor nephrectomies due to safety concerns [18]. While we acknowledge that RALDN is an expensive surgical technique, we believe that healthy living donors deserve the highest standard of care and the safest technology available. Cost savings should never come at the expense of donor safety, and for this reason, we do not feel comfortable using Hem-O-Lock clips in any minimally invasive living donor surgery. RALDN could be associated with complications such as post-operative bleeding, chyle leak or iatrogenic injury to surrounding tissue. While surgical drainage is often recommended to detect these early complications [19], no surgical drainage was placed post-operatively into any of our RALDN donors. Numerous viable living donor kidneys are declined because of surgical or anatomical factors [20]. Specifically, multiple vessels can be found in up to 8% of left kidneys and 32.5% of right kidneys [21]. The current shortage of organ donation requires a more accurate risk-benefit assessment that permits utilization of these anatomically variant organs [22]. Anatomic kidney variants were found in 25.0% (28/112) of our kidney donors. These grafts were successfully reconstructed on the back table and transplanted into our pediatric/adult recipients with no significant urologic/vascular or other surgical complications observed. These donor kidneys with multiple renal vessels do not appear to present a considerable impact on short- or longer-term graft function and graft survival [23,24]. Most of our robotically procured LDNs were left kidneys (N=99). To maintain maximum renal function in the LD, the right kidney is only extracted when the left kidney function predominates, i.e., when the right kidney presents with anatomical variants, duplicated collecting system, calcified renal arteries or multiple vessels [2] or when the difference between the left and right kidney volume favors retaining the left kidney, as in our cases. Several studies confirm that technical difficulties involved in performing right LDNs increase WIT, thereby increasing the risk of poorer early graft function [2]. Minimally invasive surgical techniques will continue to play a growing role in the field of kidney transplantation and are expected to remain the preferred approach for LDN. However, it is crucial to thoroughly assess outcomes among the kidney transplant recipients to ensure that this approach is widely accepted and adopted within the transplant community.The outcomes of kidney transplant recipients who received RALDN kidneys are described in 3 series [3,25,26]. DGF was observed in 11.5% and 2.6% of recipients in two series [25,26]. Graft loss due to renal artery thrombosis ranged from 0.4% [3] to 1.4% [26]. Additionally, renal artery stenosis occurred in 3 patients (5.7%) among 52 kidney recipients who received RALDN [25]. However, these studies did not provide comprehensive information regarding the overall outcomes of kidney transplant recipients. In our study, the cases where the right donor kidney was robotically extracted were not associated with developing DGF or graft loss.

Conclusion

We show that robotically procured living donor kidneys, even those with anatomical variants, are a safe and feasible source for transplantation. Back table vascular reconstruction of living donor grafts with vascular abnormalities can be safely implemented with no apparent increased risks of developing complications among such kidney transplant recipients.

Ethical Considerations: This study was approved by the University of Miami Institutional Review Board (IRB #20140129) and follows the ethical principles (as reviewed in 2013) of the Helsinki Declaration. All patients (or guardians in cases of pediatric patients) gave written informed consent.

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Conflict of Interest: The authors declare that they have no conflicts of interest to disclose.

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