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Robotic donor nephrectomy: optimizing outcomes beyond the limitations of laparoscopy

Franklin C. Olumba[1] · Neeta Vachharajani[1] · Jennifer Yu[1] · Meranda Scherer[1] · Sarah Matson[1] · Angela L. Hill[1] · Amen Kiani[1] · Yiing Lin[1] · Majella M. B. Doyle[1] · William C. Chapman[1] · Jason R. Wellen[1] · Adeel S. Khan[1]

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Abstract

Background Robotic donor nephrectomy (RDN) has emerged as a safe alternate to laparoscopic donor nephrectomy (LDN), offering improved visualization, instrument dexterity and ergonomics. There is still concern about how to safely transition from LDN to RDN.

Methods We performed a retrospective review of 150 consecutive living donor operations (75 LDN and 75 RDN) at our center, comparing the first 75 RDN's with the last 75 LDN's performed prior to the initiation of the robotic transplant program. Operative times and complications were used as surrogates of efficiency and safety, respectively, to estimate the learning curve with RDN.

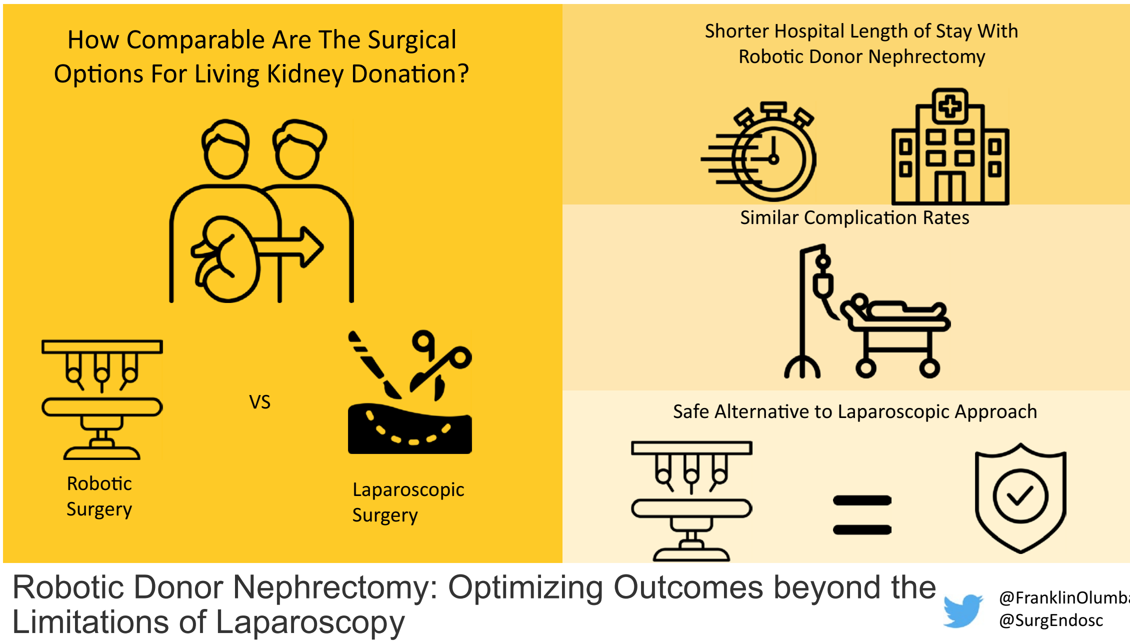
Results RDN was associated with a longer total operative time (RDN 182 vs LDN 144 min; $P < 0.0001$) but a significantly shorter post-operative length of stay (RDN 1.8 vs LDN 2.1 days; $P = 0.0213$). Donor complications and recipient outcomes were the same between both groups. Learning curve of RDN was estimated to be about 30 cases.

Conclusions RDN is a safe alternate to LDN with acceptable donor morbidity and no negative impact on recipient outcomes even during the early part of the RDN learning curve. Surgeon preferences for the robotic approach compared to traditional laparoscopy will require further scrutiny to improve ergonomics and operative efficiency.

✉ Adeel S. Khan
akhan24@wustl.edu

1 Department of Surgery, Washington University School of Medicine, 660 Euclid Ave, St. Louis, MO 63110, USA

Graphical abstract



Keywords Robotic surgery · Living donation · Kidney transplantation · Donor nephrectomy · Operative learning curve · Surgical education

Abbreviations

RDN	Robotic donor nephrectomy
LDN	Laparoscopic donor nephrectomy
RKT	Robotic kidney transplant
HPB	Hepato-pancreatico-biliary
BMI	Body mass index
ERAS	Enhanced recovery after surgery
DGF	Delayed graft function

Living donor kidney transplantation offers superior outcomes to deceased donor transplantation across an array of metrics such as graft survival, recipient quality of life, and cost-effectiveness [1, 2]. It is the optimal type of kidney transplantation but one that still comes with potential risk for the healthy donor. The preferred technical approach to the donor nephrectomy operation has rapidly transitioned over the past 25 years from the traditional open approach to the less invasive laparoscopic operation first described by Ratner et al. in 1995 [3]. Since then, multiple studies have demonstrated improved outcomes with laparoscopic technique [3–5], and in just a short 10-year period, laparoscopic donor nephrectomy (LDN) became the gold standard for living donation. Innovation in this field has continued and in 2002, Horgan and colleagues reported the first 12 successful cases of robotic-assisted living donor nephrectomy, showing good safety results [6]. Since then, the robotic technique has been established as a safe alternative to LDN, and several centers in North America have transitioned to robotic donor nephrectomy (RDN) as their preferred approach. Early studies have shown comparable outcomes to LDN with the additional benefits of improved three-dimensional visualization, improved dexterity and articulation with robotic instruments allowing for precise dissection [7–9]. The robotic approach also eliminates the need for "hand-assist" which is the most common method for LDN in the majority of transplant centers and can contribute to both patient discomfort from mechanical stretching of the hand port incision and surgeon discomfort from poor ergonomics during the operation [7–9]. Early data do not yet demonstrate clear benefit of the robotic technique over laparoscopic but many believe that it is poised for widespread adoption once more centers gain comfort with the robotic platform and overcome their projected learning curve [10, 11]. There are promising outcomes being reported with robotic kidney transplantation (RKT), especially in recipients with BMI greater than 30 compared to the traditional open approach has bolstered an increasing number of transplant centers to adopt RDN as the initial step towards developing the skills needed for the more technically challenging RKT operation. We report our initial experience with RDN in the first 75 consecutive patients over a two-year period and provide a comparison with the last 75 LDN (hand-assist) cases performed by the same surgeons and assess the safety, reproducibility and the learning curve associated with adoption of this technique.

Methods

We performed a retrospective review of our prospectively maintained database from a high-volume transplant center. The study was approved by the institutional review board of Washington University in St. Louis School of medicine and all protocols were followed. No written consent was required for this review. Approximately 300 kidney transplants are performed annually at our center, of which, nearly one quarter (approximately 70 per year) are from living donors. Over the last decade, most living donor nephrectomies at our institution were performed laparoscopically with hand-assist (LDN) by three transplant surgeons (AK, JW, MD). After initiation of the robotic transplant program in early 2020, two of the surgeons (AK, JW) transitioned from LDN to RDN. This was part of a larger effort to develop a multi-faceted robotic transplant program. That effort required training a transplant-specific OR team in robotics and building an infrastructure to progress towards excellence in robotic surgeries for several transplant and hepato-pancreatico-biliary (HPB) surgery indications including RKT and robotic living donor liver resections. This study compares the first 75 consecutive RDN with the last 75 consecutive LDN performed by two surgeons (AK and JW). One of the surgeons (AK) had considerable experience in robotic surgery (> 100 cases) and LDN (> 50 cases) while the other surgeon (JW) had an extensive (> 10-year) experience in LDN but minimal experience in robotic surgery. Both surgeons were fully credentialed in performing robotic surgery prior to robotic program initiation. Study variables included patient demographics, baseline clinical history, intraoperative variables such as operative times, conversion to open operation, requirement for blood transfusion, and post-operative outcomes in both donors and recipients. The 75 RDN procedures spanned the period from February 2020 to November 2021 while the 75 LDN procedures were performed between June 2017 and February 2020. Other than the first RDN patient, who was chosen for optimal anatomy (mid-range BMI, single renal artery, and single renal vein), there were no specific criteria utilized for choosing between robotic or laparoscopic approaches once the institutional selection criteria for living donation were met. Only cases from AK and JW were included to minimize surgeon bias. There was no difference in intraoperative or postoperative care of patients in either LDN or RDN groups, and both were managed under the institutional Enhanced Recovery after Surgery (ERAS) pathway implemented in 2016 and has been previously described [12, 13]. Complications were graded using the Clavien-Dindo classification system [14, 15].

Operative technique for RDN

Patient positioning on the operating room bed is the same for RDN and LDN patients: the table is slightly flexed at hip level with the patient in lateral decubitus on a bean bag with arms extended, supported with padding of all bony prominences.

RDN

Initial access is obtained through a 7 cm kidney extraction incision (Pfannenstiel) and GelPort containing a 12 mm assistant port is placed. Two 8-mm ports (periumbilical camera port and a subcostal working port—both in paramedian position) and a 12 mm lower abdomen midclavicular port (monopolar cautery, vessel sealer device, robotic stapler). Right sided nephrectomies often require an additional assistant port which is either a 5 mm laparoscopic port or an 8-mm robotic port for liver retraction. A transversus abdominus plane regional anesthetic block is performed at the end of each case.

LDN

Initial access is obtained through a 7 cm periumbilical midline or Pfannenstiel incision through which a hand-assist port (GelPort system [Applied Medical, Rancho Santa Margarita, CA, USA]) is inserted. This also serves as the site of kidney extraction at the end of the case. Two 12 mm ports are placed, one in the epigastric/subcostal area (camera port) and one in the lower abdomen in approximately the midclavicular line (dissection/stapler port). Occasionally, a 5 mm port is placed in the mid-lateral abdomen for kidney retraction. The kidney is extracted through the gel-port and a transversus abdominus plane regional anesthetic block is performed at the end of each case.

Intraoperative management

All patients receive approximately 2.5–3 L crystalloid intraoperatively prior to clamping of the renal vessels. Furosemide (20 mg), mannitol (12.5 gm) and heparin (2000 units) are administered intravenously 2–3 min prior to stapling of the renal vessels.

Data Analysis

Statistical analyses were performed using GraphPad Prism v 5.0 (GraphPad Software, Inc.

La Jolla, CA) and R Core Team (2022). Categorical variables were compared using Fisher's exact test. Shapiro Wilk test was used to assess distribution normality for all continuous variables. Student's T test was used to compare those normally distributed continuous variables otherwise unpaired two-sample Wilcoxon test was used. Results of continuous variables are expressed as mean with standard deviation. Categorical variables are expressed as *N* (%). For every comparison, difference with a *P* value < 0.05 was considered statistically significant.

Results

Table 1 summarizes the demographics and baseline clinical characteristics of the RDN and LDN groups. Patients in both groups were comparable in age (mean 45 ± 13 RDN vs 44 ± 14 LDN; *P* = 0.637), male gender (36% RADN vs 43% LDN; *P* = 0.504) and body mass index (BMI) (27 ± 4 RDN vs 27 ± 4 LDN; *P* = 0.994). There were also no differences between the two groups in laterality of nephrectomy (right kidney 11% RDN vs. 12% LDN; *P* = 1.000), history of previous abdominal surgery (44% RDN vs. 47% LDN; *P* = 0.869), and rate of living-related donation (43% RDN vs. 41% LDN; *P* = 1.000).

Table 1 Demographics and basic clinical characteristics of RDN and LDN groups

	RDN	LDN	*P* value
N	75	75	
Age (years)—mean (SD)	45.3 ± 13.0	44.4 ± 14.5	0.637
Male gender—*n* (%)	27 (36.0%)	32 (42.7%)	0.5039
Right sided nephrectomy	8 (10.7%)	9 (12.0%)	1.0000
BMI—mean (SD)	27.1 ± 4.2	26.8 ± 4.2	0.994
History of previous abdominal surgery—*n* (%)	33 (44.0%)	35 (46.7%)	0.8698
Living-related donation—*n* (%)	32 (42.7%)	31 (41.3%)	1.0000

RDN robotic donor nephrectomy, *LDN* laparoscopic donor nephrectomy, *SD* standard deviation, *BMI* body mass index)

Table 2 summarizes the donor kidney anatomy and intraoperative details for the cohort. All operations were completed as planned (laparoscopically or robotically), and there were no conversions to open in either group. Total operative time (TOT) (i.e., time from incision to final closure) was longer for the RDN group (mean 182 min vs 144 min; *P* < 0.0001). For the RDN group, docking time (DT) (i.e., time from incision to docking of robot including the time for port placement) was 22 ± 8.2 min, and the console time (CT) (i.e., time from docking to undocking of robot) was 122.7 ± 29.7 min. Both groups had a similar number of patients with multiple renal vessels (24% RDN vs. 25% LDN; *P* = 1.000). Twenty percent of RDN patients had > 1 renal artery compared to 24% in LDN group (*P* = 0.1178). No patient in either group required an intraoperative blood transfusion and all patients had an estimated intraoperative blood loss (EBL) within the expected range of < 150 cc except for 1 (1.3%) patient in the LDN group (EBL = 300 cc).

Postoperative donor outcomes for the two groups are summarized in Tables 3 and 4. The average postoperative length of stay (LOS) was significantly shorter for RDN patients (1.8 vs. 2.1 days; *P* = 0.021). One in three donors (32%) went home on postoperative day 1 after RDN compared to 1 in 5 (20%) for the LDN group (*P* = 0.093). The overall 90-day complication rate was comparable between the two groups. Post-operative complications (all grades) were seen in 5% of RDN and 7% of LDN cases and were comparable between the two groups. Significant complications (Clavien-Dindo III or higher) were seen in 3 (4%)

Table 2 Donor kidney anatomy and intra-operative findings for RDN and LDN groups

	RDN	LDN	*P* value
Donor kidney vascular anatomy			
Multiple (> 1) arteries OR vein	18 (24.0%)	19 (25.3%)	1.0000
Multiple (> 1) arteries only	15 (20.0%)	18 (24.0%)	0.6938
Multiple (> 1) veins only	3 (4.0%)	1 (1.3%)	0.6199
Multiple (> 1) arteries AND veins	2 (2.7%)	0 (0%)	–
Number of arteries			
1	60 (80.0%)	57 (76.0%)	0.1178
2	12 (16.0%)	18 (24.0%)	
3	3 (4.0%)	0 (0%)	
Total operative time (TOT) (min)—mean (SD)	182 ± 32	144 ± 23	< 0.0001
Docking time (DT) (min)—mean (SD)	22.2 ± 8.2	N/A	
Console Time (min)—mean (SD)	122.7 ± 29.7		
Conversion to open surgery	0	0	

TOT total operative time, *DT* docking time, *CT* console time, *SD* standard deviation)

Table 3 Postoperative outcomes for RDN and LDN groups

Variable	RDN	LDN	*P* value
Postoperative LOS (days)—mean (SD)	1.8 ± 0.7	2.1 ± 0.7	0.0213
Number of donors discharged on POD1	24 (32.0%)	15 (20.0%)	0.0939
Postoperative complications (all grades)—*n* (%)	4 (5.3%)	5 (6.67%)	1.0000
Complication severity (Clavien–Dindo grade)—*n*			0.6199
I	1	3	
II	0	1	
IIIa	3	0	
IIIb	0	1	
IV or V	0	1	
Postoperative 90-day complications—none	71 (94.6%)	70 (93.3%)	1.000

All complications are graded using Clavien–Dindo grading system with grade III or higher considered as significant complications. (*LOS* length of stay, *POD* post-operative day, *SD* standard deviation)

Table 4 Details of operative complications and management for RDN and LDN groups

	Complications	Intervention	Clavien–Dindo grade
Robotic donor nephrectomy ($n = 75$)	Wound infection	PO antibiotics	I
	Chylous ascites	Diagnostic paracentesis, low fat diet	IIIa
	Pneumothorax	Tube thoracostomy	IIIa
	Contained bladder perforation	Percutaneous drain placement	IIIa
Laparoscopic donor nephrectomy ($n = 75$)	Incisional neuropathy	Gabapentin (po)	I
	Wound drainage	Bedside probing, PO antibiotics	I
	Incisional hernia	Observation	I
	Rectus sheath hematoma	2 unit PRBC transfusion, observation	II
	Incisional hernia	Robotic repair with mesh	IIIb

patients in the RDN group (pneumothorax, chylous ascites, and contained extra peritoneal perforation of the urinary bladder—all Clavien-Dindo grade IIIa) and 1 (1.3%) patient in the LDN group (incisional hernia at the port site requiring laparoscopic repair—Clavien-Dindo grade IIIb). There were no grade IV or V complications in either group.

Recipient outcomes

All procured kidneys from RDN and LDN were safely transplanted with no complications that could be attributed to the donor operation. Two patients in each group developed DGF (2.6% RDN vs 2.6% LDN). One-year graft survival rate was 98.6% in RDN (1 graft loss from renal artery thrombosis unrelated to RDN operation) and 100% in LDN recipient group and 1-year patient survival was 100% for both groups.

Learning curve for RDN

The learning curve for RDN was assessed using variables pertinent to operative time, estimated blood loss, transfusion requirements and complications. Supplemental Table 1 compares the first half (patients 1–38) with the second half (patients 39–75) of the RDN cohort. There was a significant improvement in console times for the latter half of the robotic experience (125 vs. 110 min; $P = 0.033$). This difference became more pronounced when the comparison was done between the first 20 and the last 20 patients (console time 126 min for first 20 patients vs 104 min for last 20 patients; $P = 0.0032$). All the complications in RDN group occurred in the first half of the experience (4 vs 0). There were no differences in intraoperative blood loss and transfusion requirements across groups.

Discussion

Robotic surgery was incorporated into our transplant program in 2020. We started the program with the goal of offering an innovative surgical approach to an increasing number of living donation candidates felt to be higher risk for open or laparoscopic surgery due to obesity or medical comorbidities. The decision was facilitated by the increasing experience in non-transplant robotic surgery (HPB and general surgery) of faculty at our institution, the increasing availability of robotic block time, and the desire to streamline operations through a dedicated OR team with both transplant and robotic expertise. We were also encouraged by recent reports from several centers that demonstrated safety and feasibility of robotic surgery in kidney transplantation, especially for patients with obesity [16].

This study reports our initial RDN experience which aimed to assess safety and reproducibility as well as estimate our learning curve for this operation. With exception of the first patient in the RDN group, there was no intentional patient assignment to either LDN or RDN, with near identical demographic, clinical, and anatomic data presented in Tables 1 and 2. Not surprisingly, the total operative time was longer for RDN patients by 38 min. The actual operative time (console time) for the RDN group was approximately 2 h (123 min) and this console time improved from the first half to the second half of the RDN group by 15 min ($P = 0.033$). This suggests increasing familiarity of the team with the operation and progress of the surgeons along the learning curve for which one can expect continued progress.

Safety of RDN

Analysis of variables associated with safety of an operation (e.g., intraoperative complications, estimates of blood loss, need for intraoperative and/or postoperative transfusion and general postoperative course and complications) showed no difference between the two groups. This suggests that RDN is a safe alternate to LDN even during the early stages of adoption and can be implemented effectively by experienced transplant surgeons as a dedicated robotic transplant team is developed. The overall complication rates were quite low for both RDN and LDN groups with no patients requiring return to the operating room or complications resulting in multi system organ failure and/or death, like previously reported literature [17, 18]. Of the three significant complications (Clavien-Dindo grade III or higher) in the RDN group, one (tube thoracotomy for pneumothorax due to small hole in right diaphragm noted during surgery and repaired) can be attributed to the early learning curve of RDN. The association of the other two (chylous ascites and contained extra peritoneal bladder perforation at site of Pfannenstiel incision) with robotic technique appears less probable. The patient with the bladder perforation had multiple prior lower abdominal surgeries with tethering of the bladder to abdominal wall seen on preoperative imaging. All three complications occurred in the first half of the robotic experience with no significant complications seen in the second half of the cohort. Of note, our technique for donor nephrectomy does differ slightly from other robotic donor reports in that we utilize a Pfannenstiel incision for gelport hand-assist and kidney extraction. This is notable for its association with lower post-operative hernia complication which was not compared between the two groups as the technique is utilized in both cohorts [19, 20]. This technical point is one we highly recommend for others looking to transition to the robotic platform if not already utilized routinely in the laparoscopic setting.

Several reports have suggested decreased postoperative pain and improved recovery with robotic surgery compared to the laparoscopic approach. The mechanism behind this observation is felt to be related to the relative fixation of the robotic trocars in the abdominal wall which leads to minimal stretching of tissue around the ports [21]. Desai et al. reported their outcomes in a prospective randomized study comparing robotic and laparoscopic donor nephrectomy and demonstrated a significantly reduced postoperative analgesia requirement in the robotic group [18, 22]. Though we did not compare the analgesic requirement between the two groups in this study, the significantly shorter post-operative hospital stay in the robotic group may support the observation that the robotic approach carries less morbidity related to incisional pain than the laparoscopic technique. One in three patients in the RDN group went home on post-operative day 1 compared to one in five in the LDN group, despite following identical postoperative management ERAS pathways.

Learning curve

As a new surgical technique, the advent of RDN at our institution required a learning curve for all members of the operative team. This is shown in the longer total operative and console times during the first half of the study cohort. Based on this experience, the RDN learning curve for surgeons experienced in laparoscopic donor nephrectomy seems to be 30 cases if operative time is used as a metric. The difference in operative time was more pronounced between the first 20 cases and the last 20 cases suggesting possible continued improvement in operative times beyond the 75 cases included in this study. Interestingly, the operative times for the novice robotic surgeon who had extensive (> 10 years) experience in LDN were less than those for the HPB-experienced robotic surgeon who had considerably less overall experience in LDN. This suggests that the experience gained from the LDN operation is transferable to the robotic technique and can help shorten the learning curve and be conducive to safe implementation of RDN [17].

Hospital perspective

Cost is the ultimate consideration for many groups and their c-suite counterparts when discussing adoption of any new technology or technique. For a growing number of specialties and operations, the robotic platform has increasingly justified its higher cost in terms of other savings and we believe the same will be true for the RDN soon [23, 24]. The robotic platform itself has a high upfront cost but just as with any other operative tool this is absorbed across multiple surgical services as it can be used for many operations. While there is certainly higher cost associated with a longer operative time for the RDN, the total cost of the admission could be lower given the decreased length of stay. Further studies by our group are ongoing to determine whether these two costs offset each other as we anticipate they will, especially as OR time decreases for RDN with greater experience.

Trainee perspective

Abdominal transplant surgery fellows are increasingly proficient on the robotic platform due to the experience gained in residency. In our experience, there is natural variation in proficiency learning the RDN associated with the amount of prior experience in residency [25]. We believe it is arguable whether experience in LDN in addition to RDN is necessary given the growing interest in adding robotic transplant programs by many transplant centers worldwide. Performing more RDN cases has thus resulted in improved job prospects for our recent fellows who have increasingly found jobs that require either setting up a robotic program or taking leadership roles in an existing one.

Surgeon perspective

LDN is an established technique with a very good safety profile and has been the gold standard for donor nephrectomy for many years [4, 5, 8, 9]. The decision to transition to RDN may not be easy for many institutions, especially for transplant surgeons who have not previously trained in robotic surgery. Despite this initial hurdle in robotic implementation, we feel there are many advantages to the robotic approach that are difficult to quantify especially due to the variation in technique among groups reporting outcomes. Robotic instruments are more advanced than their laparoscopic counterparts and allow meticulous tissue dissection, enhanced visualization, and significantly improved ergonomics for the operating surgeon, who is seated at the console instead of standing at the bedside. We feel that the robotic approach makes the operation easier in patients with obesity and in those with more complex vascular anatomy, which could potentially help expand the pool of living donor candidates in the current environment of high obesity prevalence among the general population. Robotic donor operations enable creation of a dedicated robotic transplant team and can hone the skills needed for robotic kidney transplantation, a key reason for initiating the robotic program at our center. This must be weighed against the higher cost associated with use of the robot and any institution-specific logistical challenges related to availability of the robot.

Limitations

Our study was mainly limited by the small sample size and short time frame, though the high-volume at our center allowed us to demonstrate the rapid acquisition of skills related to RDN in the surgeon learning curve. This was a single center, retrospective review using a smaller case series, and further extrapolation of our data may be restricted. We also recognize that the differences in length of stay between the LDN and RDN cohorts could be attributed to other factors given that the LDN cohort was from an earlier period than the RDN cohort. One such factor could be the overall trend of decreasing hospital stay in recent times. However, when we compared length of stay with a separate smaller group of LDN patients ($N=41$) that underwent surgery during the same period as our RDN cohort by a different surgeon, we still found a shorter length of stay in the RDN group (1 in 4 patients discharged on POD 1 in the RDN group vs 1 in 3 patients discharged on POD 1 in the contemporary LDN group; $P=0.5225$). This difference was not significant likely due to the smaller number of patients in the contemporary LDN cohort.

Conclusions

RDN is a safe alternate to LDN with an acceptable donor morbidity and no negative impact on recipient outcomes. While the operative times are longer with RDN, the patients have a shorter post-operative length of stay which can result in a faster overall recovery and decrease overall cost associated with the operation. Based on our initial experience, the RDN learning curve for surgeons experienced in donor nephrectomy is about 30 cases and does not seem to be impacted by prior non-transplant robotic experience.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00464-023-10246-z.

Declarations

Disclosures William C. Chapman is on the board of directors for Mid-America Transplant. Adeel Khan and Meranda Scherer are paid proctors for Intuitive Surgical, and Jason Wellen is a paid consultant to Intuitive Surgical for education on robotic nephrectomies. The remaining authors Franklin Olumba, Neeta Vachharajani, Jennifer Yu, Sarah Matson, Angela Hill, Amen Kiani, Yiing Lin and Majella Doyle have no conflicts of interest or financial ties to disclose.

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