ORIGINAL ARTICLE

Robotic Assisted Living Donor Nephrectomies

A Safe Alternative to Laparoscopic Technique for Kidney Transplant Donation

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Objective: To review outcomes after laparoscopic, robotic-assisted living donor nephrectomy (RLDN) in the first, and largest series reported to date.

Summary of Background Data: Introduction of minimal invasive, laparoscopic donor nephrectomy has increased live kidney donation, paving the way for further innovation to expand the donor pool with RLDN.

Methods: Retrospective chart review of 1084 consecutive RLDNs performed between 2000 and 2017. Patient demographics, surgical data, and complications were collected.

Results: Six patients underwent conversion to open procedures between 2002 and 2005, whereas the remainder were successfully completed robotically. Median donor age was 35.7 (17.4) years, with a median BMI of 28.6 (7.7) kg/m^2. Nephrectomies were preferentially performed on the left side (95.2%). Multiple renal arteries were present in 24.1%. Median operative time was 159 (54) minutes, warm ischemia time 180 (90) seconds, estimated blood loss 50 (32) mL, and length of stay 3 (1) days. The median follow-up was 15 (28) months. Complications were reported in 216 patients (19.9%), of which 176 patients (81.5%) were minor (Clavien-Dindo class I and II). Duration of surgery, warm ischemia time, operative blood loss, conversion, and complication rates were not associated with increase in body mass index.

Conclusion: RLDN is a safe technique and offers a reasonable alternative to conventional laparoscopic surgery, in particular in donors with higher body mass index and multiple arteries. It offers transplant surgeons a platform to develop skills in robotic-assisted surgery needed in the more advanced setting of minimal invasive recipient operations.

Keywords: donor obesity, laparoscopic, living donor, nephrectomy, outcomes, perioperative, robotic

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Living donor nephrectomy represents a unique surgical situation, where surgery is performed on a healthy individual for the benefit of another patient, rather than a patient solely being subjected to operative intervention. Similarly, donation is supported to allow for donor-recipient relationships to flourish. Donor morbidity is of paramount importance because of the altruistic component of live donation and the lack of patient pathology. The surgical technique must be balanced; provide precise, cosmetically appealing results, minimize pain, and optimal functional outcome for the donor without jeopardizing the integrity of the allograft for the recipient. Since the introduction of laparoscopic donor nephrectomy (LDN) by Ratner in 1995,[1] unrelenting efforts have been made in this field and the operative technique is continuously evolving. Long term studies have confirmed non-inferior outcomes compared to open donor nephrectomy with the appeal of laparoscopy and its donor benefits expanding the donor pool.[1–3] These findings have propelled LDN to be the standard of care at most transplant centers.[4]

Although minimally invasive techniques have improved the volume of live donation, the general population is growing more obese, causing optimal donors to become a rare occurrence; posing the donor dilemma of accepting obese donor candidates. According to the National Health and Nutrition Examination Survey, the prevalence of obesity between 2007 and 2008 was 32.2% and 35.5% among adult men and women, respectively, representing a greater than 100% increase from 1976 to 1980.[5] A recent study concluded that if the trends continue, there will be a 30% increase in obesity prevalence over the next 2 decades.[6] Obesity has been associated with medical complications,[7,8] and based on the potential for short-term and long-term safety issues, transplant programs have implemented body mass index (BMI) cutoffs for obese donors.[9] The introduction of laparoscopic techniques has not only facilitated more donors incurring the risk of a surgical procedure, but it has also allowed obese donors to experience comparable recoveries to their nonobese counterparts.[10]

Robotic assisted donor nephrectomy offers some potential advantages over laparoscopy with the stability of the camera, and the optical 3-dimensional magnification it provides. We hypothesized that these qualities would ensure safety in complex cases involving vascular anomalies and obese donors.

In this context, our center was the first to utilize robotic-assistance for LDN in the year 2000,[11,12] and to adopt this approach as the standard operation. We continue to use this technique and are reporting the largest series of robotic-assisted living donor nephrectomy (RLDNs) to date. The primary objective is to analyze our donor outcomes, with a particular interest in how donor characteristics affect operative outcomes, and evaluating temporal trends in the donor pool. Furthermore, we compare our donor outcomes from RLDN to the published laparoscopic living donor nephrectomy studies available.

METHODS

Study Design

This is a single-center retrospective review of all living donors who underwent RLDN from September 2000 to December 2017. The Institutional Review Board at the University of Illinois at Chicago approved the study. A database was established incorporating United Network for Organ Sharing data and retrieval of donor information from the electronic medical record. Clinical and demographic characteristics, operative details and outcomes, specifically categories of perioperative complications (per the Clavien-Dindo classification[13]), operative time (ORT; from initial incision to skin closure encompassing docking and robotic time), warm ischemia time (WIT), estimated blood loss (EBL), length of stay (LOS), and 30-day hospital readmission rate were reviewed. The Clavien-Dindo system does not specifically address the intraoperative vascular complications arising from donor nephrectomy, so we used a previously described modification to the Clavien-Dindo classification system to incorporate these events.[14] All surgical complications occurring within 30 postoperative days were classified as perioperative and subsequent events were defined as delayed complications. Renal function was evaluated with serum creatinine at hospital discharge, and at 1-year follow up; systolic and diastolic blood pressure were assessed at 1-year and any development of end-stage renal disease (ESRD) post-donation was noted. To assess the effect of donor obesity and temporal trends of the complications and outcome, living donors were divided into different BMI groups based on the World Health Organization classification[15] and different eras.

Donor Selection and Evaluation

The selection criteria and evaluation have been described previously.[11,12] All living donor transplants were approved by United Network for Organ Sharing after undergoing comprehensive medical, psychosocial and nutritional assessment. A donor advocate assesses all the candidates as part of the preoperative work up to ensure all ethical standards were upheld. All donors were healthy volunteers without concomitant co-morbidities. Imaging evaluation includes computed tomographic angiogram with 3-dimensional reconstruction of the renal vessels and collecting system to evaluate for anomalies. After review by the multidisciplinary committee, the donors were selected for donor nephrectomy and signed an informed consent for the procedure. The left kidney is routinely preferred for safer donation; however, the right kidney was chosen in the presence of any anomaly (benign lesions or worse split function compared to the left kidney), aiming at optimizing donor safety by retaining the ''healthiest'' kidney for the donor.

Surgical Procedure

Donor nephrectomies were performed with the da Vinci Robotic Surgical System, (Intuitive Surgical, Sunny Valley, CA) using four 7-mm trocar incisions and a 7-cm hand-assistance port for extraction of the organ. The details of the surgical operation have been previously described.[11,16,17] At its inception, this procedure entailed a small vertical midline infra-umbilical incision for hand assistance, but was later modified in 2008 to a suprapubic Pfannenstiel incision to minimize wound complications.

Postoperative Care and Follow Up

All donors were extubated before leaving the operating room. Venous thromboembolic prophylaxis was administered before surgery and continued until discharge by employing pharmacologic and mechanical means, with early ambulation on the evening of surgery. Multimodal pain therapy was instituted. The donors were allowed clear liquids the day of surgery and progressive diet advancement as tolerated. Urinary catheterization, peripheral intravenous fluids, and other monitoring devices were discontinued beginning the morning after surgery. Routine laboratory tests (complete blood count, basic metabolic panel) were performed as indicated until discharge. Patients were discharged once tolerating a regular diet and ambulating with adequate pain control. The donors had their first follow up on the 10th post-operative day. Routine laboratory tests were repeated after 1 month, follow by periodic follow up for 2 years to monitor renal function.

Data Collection

The total ORT was defined as the interval of time between skin incision to skin closure and included the docking time for the robotic system. WIT was the interval from renal artery occlusion to back-table perfusion with preservation solution. LOS encompassed day of admission to day of discharge after donation. Operative complications included any unexpected event leading to injury (donor or allograft). Donor postoperative complications were captured from a review of Emergency department visits, in-patient hospitalizations, and clinic follow-up visits. The recipient outcomes were recorded, including assessment of ureteral complications, presence of delayed graft function (DGF) (defined as need for dialysis within 7 days of transplant), evaluation of graft function (serum creatinine) at discharge and 6 months after transplant, and long-term patient and graft survival.

Statistical Analysis

Subjects with missing data were excluded from analysis as noted in the tables. Categorical variables were compared using Chi-square or Fisher exact test, where appropriate, and continuous variables were compared using analysis of 1-way variance or Kruskal-Wallis test for non-normal data. A $P < 0.05$ was considered statistically significant. All analysis was carried out using IBM SPSS Statistics for Macintosh version 25.0 (Armonk, NY: IBM Corp).

RESULTS

Donor Demographics

Between September 2000 and December 2017, 1090 donor nephrectomy cases started robotically with a conversion rate of 0.6% (7 patients), leaving 1084 robotic-assisted donor nephrectomies completed successfully. The donor demographics are summarized in Supplemental Tables, http://links.lww.com/SLA/C331. The median and interquartile range for donor age was 35.7 (17.4) years (range 18–72) with a majority of donors being female (55.1%). The BMI ranged from 16.4 to 51.9 kg/m^2 with a median BMI of 28.6 (7.7) kg/m^2. The majority of donors were biologically related to their recipients (70.9%). The proportion of left kidneys procured was 95.2%. Arterial variations were present in 24.1% of donors with 2, 3, and 4 arteries present in 21.3%, 2.5%, and 0.3% of donors, respectively. Venous variations were present in 23 patients.

Perioperative Measurements

The median ORT, WIT, and EBL were 159 (54) minutes, 3.0 (2.5) minutes, 50 (32) mL, respectively. Four patients (0.4%) required blood transfusions. EBL was reported to be 100 mLs or less in 91.8% of cases, whereas 6.9% had an EBL up to 500 mLs and only 1.3% of cases had an EBL of >500 mLs. The median LOS was 3

(1) days with a readmission rate of 7.9%. Median follow up was 15 (28) months for the cohort. Median 1-year creatinine was 1.2 (0.4) mg/dL. Outcomes are summarized in Supplemental Table 2, http://links.lww.com/SLA/C331.

Donor Morbidity and Mortality

Overall, there were 216 (19.9%) complications reported among donors during the follow up period, with 188 patients (17.3%) noted within 30 days of surgery, and 28 (2.6%) presenting as delayed complications (see Supplemental Table 3, http://links.lww.com/SLA/C331). Of the 188 early complications, the majority were Clavien-Dindo Grade I [110 patients (10.1%)] and Grade II [51 patients (4.7%)] followed by Grade III [18 patients (1.7%)]. Five grade IV complications were reported: 2 patients with pulmonary embolism, 2 patients with retroperitoneal hematomas, and 1 case with hemoperitoneum secondary to anterior abdominal vessel bleeding. The hemoperitoneum was evacuated under laparoscopic exploration, and the bleeder ligated. One of the retroperitoneal hematomas was observed and discharged home on postoperative day 4, after imaging and laboratory investigations confirmed the absence of ongoing hemorrhage, whereas the other was taken back to surgery for hematoma evacuation. One death (Grade V) was observed in a donor who succumbed to intraabdominal sepsis of unknown etiology, with no identifiable bowel injury on autopsy. Six cases (not included in this dataset) required conversion to open procedures whereas 1 to laparoscopy due to robotic system malfunction (0.6%). The open conversions were due to intraoperative bleeding during kidney procurement with 4 occurring as a consequence of a stapler misfire early in our experience (2002–2005) and 2 were due to accidental transection of an upper and lower polar artery and vein, respectively.

Of the twenty-eight delayed complications, 7 were incisional hernias repaired laparoscopically, 3 were cases of small bowel obstruction requiring surgical intervention, and 3 abdominal scar contractures requiring abdominoplasty (Grade III; found in Supplemental Table 4, http://links.lww.com/SLA/C331). Two patients developed ESRD (Grade IV) due to unknown etiology in 1 patient, and focal segmental glomerular sclerosis in the other. They were both monitored closely and underwent renal transplantation 8 and 11 years after initial nephrectomy respectively.

Effect of Donor Obesity on Clinical and Perioperative Outcome Variables

There were 427 (39.4%) donors with a BMI $\geq 30\,kg/m^2$, 370 donors in the overweight group, and 259 (23.9%) of donors with normal BMI (total $n = 1056$). Obese donors with BMI ≥ 40 were more likely to be younger than their overweight and normal BMI, and class 1 obese counterparts ($P = 0.005$). There were more female donors with increase in BMI class ($P = 0.011$). Obesity was more prevalent in African-American donors, followed by Hispanics donors ($P = 0.001$). EBL, transfusion requirements, hospital LOS, readmissions, and complication rates were not statistically significant when comparing the BMI groups. Creatinine on hospital discharge appeared statistically significant ($P = 0.016$); however, post-hoc testing with Bonferonni corrections did not identify any differences across the BMI sub-groups. On close inspection of the BMI groups, the ORT was longest in patients with BMI ≥ 40; however, this finding was not significant ($P = 0.106$). Open conversion rates did not seem to be associated with BMI class ($P = 0.766$).

Temporal Trends in Clinical and Perioperative Characteristics

From the year 2000 to 2016, a gradual increase in donor age was observed ($P < 0.001$; in Supplemental Table 5, http://links.lww.com/SLA/C331). Female donors comprised majority of donors in the most recent time period ($P = 0.033$), whereas the median BMI remained statistically unchanged ($P = 0.156$). The proportion of donors with African-American and Hispanic ethnicity declined over time, whereas the proportion of donors of White and other ethnicities have seen a surge over the last 8 years. Statistically significant increases were noted in ORT ($P < 0.001$), and WIT ($P < 0.001$) in the more recent time periods, whereas and LOS decreased significantly in the most recent period ($P = 0.001$). Complication rates decreased significantly over time ($P = 0.008$), whereas the readmission rates declined after an initial peak at 32.5% during the first 5 years ($P < 0.001$).

DISCUSSION

Herein we present the largest reported series on RLDN reported to date. The analysis of our experience resulted in a number of important findings. First, RLDN assessed across a variety of obese BMIs is an overall safe operation. The donor demographics in our series comprises a majority of obese donors. Despite the higher BMI within our cohort, ORT, EBL, WIT, and LOS were lower than most reported laparoscopic studies, even though obesity does add to the complexity of the procedure, extending ORT and WIT. Second, the proportion of perioperative complications declined as the robotic experience increased. There was some increase in ORT and WIT of our cohort over time, which we attributed to the introduction of new console surgeons.

Overall, RLDN is a safe surgery, though not without risks such as donor death. In a survey of US centers, Matas et al reported a perioperative mortality rate of 0.03 in LDs.[18] A study by Schold et al analyzed living donor mortality from Scientific Registry for Transplant Recipient data and compared it to operative mortality of 3,011,628 cholecystectomies, 2,262,065 appendectomies, and 13,461 nephrectomies for nonmetastatic carcinoma during the same time period and reported to the National Inpatient Sample.[19] These 2 registry comparisons revealed a live donor mortality of 0.17%, which was comparable to the mortality of patients undergoing a cholecystectomy 0.15%, and less than those having appendectomies or nephrectomies (0.40% and 0.42%, respectively). However, donor mortality has been noted to go under reported. However, with our outcomes, we show that our mortality rate is consistent with the current literature and a rare occurrence.[20]

Our donor population presented with a high percentage of obesity with a median BMI of 28.6 (interquartile range: 7.7) kg/m^2, which is higher than most reports.[10,21–24] Our program adopted a policy to carefully vet and accept obese donors, who are otherwise healthy, to continue to provide the benefits of transplantation to ESRD patients. With the rise of obesity in the United States, our donor population has become increasingly obese, and our cohort shows the safe utility of this technique for complex donor surgery.

To compare our results to laparoscopic nephrectomy, we reviewed case series that included more than 300 patients (Supplemental Table 6, http://links.lww.com/SLA/C331).[25–34] We focused on donor parameters such as: ORT, WIT, rate of conversion to open surgery, and transfusion needs during the procedure.

Our ORT and WIT were not associated with elevation in donor BMI. Extensive ORT has posed donor risk for complications such as rhabdomyolysis that could lead to RF.[35,36] It has been previously reported that BMI alone does not prolong ORT during laparoscopic nephrectomy,[37–39] but rather the anterior perinephric fat thickness can obscure structures increasing the difficulty of dissection. Anderson et al. found that for each 1 mm increase in perinephric fat, the ORT increased by 7 minutes.[37] Donor age and quantity of arteries have been noted to affect ORT significantly, consistent with the literature.[40,41] In prior studies, ORT has been affected by donor sex[42] because of the differences in perinephric fat and kidney side[39] presumably because anatomical differences and ease with access to the organ. When reviewing the mean ORT in all of these high volume laparoscopic, our median ORT of 159 minutes is the shortest reported suggesting an advantage to our technique even with a more obese cohort.[27,31,39] Similarly, the reported WIT ranges from a mean of 3.5 to 6.5 minutes, compared to our median of 3 minutes, a shorter time to preservation. Though WIT up to 10 minutes in LDN has been regarded as a safe limit,[43] a shorter WIT is optimal to protect against DGF. Thus, robotics can both be efficient and positively influence parameters important to graft function and donor outcomes.

Conversion rates ranged between 0.2% and 3.7% in the laparoscopic series reviewed, while a conversion rate of 0.6% was obtained in our cohort. Furthermore, these conversions were due to staple line bleeding, which we resolved in our series by applying polymer (Hem-o-Lok) clips at the staple line. The reported rate of intraoperative blood transfusion is variable,[33,42] ranging from 0.2% to 1.6%, with our experience closer to the lower range in the spectrum at 0.5%. Regarding recipient outcomes, one of the laparoscopic series reported a 0.3% graft thrombosis rate[27] whereas another reported 2.1%[33]; our vascular thrombosis rate was 0.4%, with the remaining series not reporting thrombosis rates.

Our series perioperative complication rate was 17.3%, which is comparable to the laparoscopic studies with reported complication rates ranging from 6% to 22.5%.[19,44–48] More specifically, major complications (Grade III or greater) in all the laparoscopic series we reviewed ranged from 1.2% to 4.5%. The current robotics series had 24 cases experience a major complication (2.2%), on the lower end of the spectrum. From a purely technical point of view, the robotic system offers several potential advantages over laparoscopy, including high definition 3-dimensional view, and wrist articulation to facilitate the procedure. It is important to note that the complications due to our procedural technique are similar to the published laparoscopic data, enhancing RLDN's claim as a noninferior approach.

Controversial reports regarding the effect of laparoscopy on the early function of the graft showed a higher proportion of DGF compared to open technique.[26,49] A meta-analysis including over 3700 donor nephrectomies performed laparoscopically concluded that there were no significant differences in the rates of DGF compared to open technique.[47] The reported rate of DGF is variable depending on the series ranging from 1.1% to 5.3%. We observed a 1.6% rate of DGF in our cohort, comparable result to the literature in LDN.[25,33,34]

The temporal evaluation of our robotic technique revealed significant increase in the ORT and WIT. These intraoperative characteristics could be ascribed to the introduction of new surgeons to the console as the technique was standardized at our institution. Donor complications have; however, decreased due to the lessons learned with experience in taking care of these individuals. On the other hand, the introduction of robotics at our program temporally occurred during an increase in live kidney donation rate at our center from 13% to 31%, at a time when living donation plateaued nationwide. Providing prospective donors—especially marginalized overweight donors—a nuanced description of the new innovations in our technique coupled with safety of the procedure in complex donors may have contributed to our institution's experience.

The present study has limitations, the foremost being the retrospective nature with its inherent shortcomings. Given the long-time span of observation, there were missing data, that could impact the results. Long-term medical and surgical outcomes beyond the initial 2 years post donation were not meticulously assessed; as our records are limited to patients who chose to return to our facility for ongoing care. At the same time this was all completed at a single center which may not have the same outcomes elsewhere. We believe that the creation of a mandatory and audited donor registry, with cost coverage for continued follow up would greatly enhance the understanding breadth and depth of living kidney donation consequences.

RLDN is a safe technique, which offers the advantages of better ergonomics to facilitate the safety of the operation in a large range of donor BMI. The ergonomic design of the robot, simulates conducting open surgery in a laparoscopic environment. It could be a reasonable alternative to conventional laparoscopic surgery as it offers shorter ORT and WIT, limited blood loss, and fast patient recovery particularly in obese donors. One may argue why, despite all these potential benefits, robotic nephrectomy has not grown as quickly as expected in the transplant world. One potential explanation could be the limited viability of the technology in the early 2000's, or its almost exclusive utilization by the urology/gynecology divisions back in those days. Moreover, when the donor population was on average leaner, hence surgeries going ''smoother,'' the potential benefit of one technology compared to another was difficult to assess, if ever present. As the population is growing more obese, adapting techniques to continue to allow for living donation will further improve the lives of ESRD patients. By preserving donor safety and maintaining optimal graft function, RLDN can serve as an equitable approach to kidney donation.

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