Robotic Versus Laparoscopic Donor Nephrectomy: A Retrospective Bicentric Comparison of Learning Curves and Surgical Outcomes From 2 High-volume European Centers

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Background. Although laparoscopic donor nephrectomy (LDN) represents the gold-standard technique for kidney living donation, robotic donor nephrectomy (RDN) settled as another appealing minimally invasive technique over the past decades. A comparison between LDN and RDN outcomes was performed. **Methods.** RDN and LDN outcomes were compared, focusing on operative time and perioperative risk factors affecting surgery duration. Learning curves for both techniques were compared through spline regression and cumulative sum models. **Results.** The study analyzed 512 procedures (154 RDN and 358 LDN procedures) performed between 2010 and 2021 in 2 different high-volume transplant centers. The RDN group presented a higher prevalence of arterial variations (36.2 versus 22.4%; $P=0.001$) compared with the LDN cohort. No open conversions occurred; operative time (210 versus 195 min; $P=0.011$) and warm ischemia time (WIT; 230 versus 180 s; $P<0.001$) were longer in RDN. Postoperative complication rate was similar (8.4% versus 11.5%; $P=0.49$); the RDN group showed shorter hospital stay (4 versus 5 d; $P<0.001$). Spline regression models depicted a faster learning curve in the RDN group ($P=0.0002$). Accordingly, cumulative sum analysis highlighted a turning point after about 50 procedures among the RDN cohort and after about 100 procedures among the LDN group.Higher body mass index resulted as an independent risk factor for longer operative time for both techniques; multiple arteries significantly prolonged operative time in LDN, whereas RDN was longer in right kidney procurements; both procedures were equally shortened by growing surgical experience. **Conclusions.** RDN grants a faster learning curve and improves multiple vessel handling. Incidence of postoperative complications was low for both techniques.

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INTRODUCTION

Living donor kidney transplantation (KT) represents the best treatment option for patients with end-stage renal disease[1]; shorter cold ischemia time, lower rejection rate, improved graft survival, and easier access to preemptive KT are just a few of the several advantages of living compared with deceased donor KT.[2,3]

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The introduction of laparoscopic donor nephrectomy (LDN) represented a milestone in the development of surgical technique for living kidney donation, providing less postoperative pain, shorter hospital stay, faster recovery, better cosmetic outcomes, and very low incisional hernia rate compared with the traditional open surgery.[4] Starting from the first report of LDN by Ratner et al,[5] this minimally invasive approach gained a widespread application and significantly contributed to the improvement of living kidney donations in the United States and worldwide[6]; as a consequence, LDN is currently considered the gold standard for living donor nephrectomy.

Another pivotal technical evolution was provided a few years later, in 2001, with the application of the DaVinci technology to living kidney donation and the development of robotic donor nephrectomy (RDN) from the Chicago group.[7,8]

Similar to LDN, the robotic approach was extensively used around the world with several technical variations,[9] but its higher costs[10,11] and the relatively similar results of RDN compared with LDN[12,13] partially limited its diffusion. Although RDN might offer several advantages compared with LDN, such as the usage of EndoWrist instruments that facilitate suturing and knotting, stable 3-dimensional visualization of the operative field, and higher surgeon comfort,[14] such benefits are difficult to measure objectively and rely on surgeons' feedback.

Only a few articles focused on the comparison of these 2 approaches to living donor nephrectomy, but current evidence is limited by small sample size.[10,12,13,15-17] In this retrospective bicentric study, we sought to compare the results of LDN and RDN performed in 2 high-volume European transplant centers, focusing on patient selection, learning curves, and postoperative outcomes of the 2 techniques.

PATIENTS AND METHODS

The study protocol followed the 2000 Declaration of Helsinki and the 2008 Declaration of Istanbul ethical guidelines; all the participants involved in the study gave their explicit informed consent for data collection and publication.

Local ethical committees' review of the protocol deemed that formal approval was not required owing to the retrospective, observational, and anonymous nature of this study. Results are reported according to Strengthening the Reporting of Observational Studies in Epidemiology.[18]

Study Design

The study enrolled all adult donors (age ≥18 y) who underwent RDN (Niguarda Hospital, Milan, Italy) or LDN (University Hospital of Padua, Padua, Italy) in 2 high-volume transplant centers between 2010 and 2021.

Both centers ranked within the first national quartile of living donor KT surgical volume during the whole study period, qualifying as high-volume centers.

The LDN program at the University Hospital of Padua was introduced in 2001: LDN cases were consecutively enrolled from the beginning of the surgical experience of a single senior consultant (L.F.) back in 2010, whereas the procedures performed by other surgeons were excluded from the analysis to depict a single-operator learning curve.

Conversely, the RDN program at Niguarda hospital began in 2010: almost all RDN cases were consecutively performed by a single senior consultant (A.G.) with no previous experience in LDN and limited experience in robotic surgery. Similar to LDN, the procedures performed by other surgeons were excluded from the analysis to depict a single-operator learning curve.

All data were retrieved from 2 university-affiliated transplant center prospective databases and anonymized before analysis.

Study Aim

The primary aim was to compare the learning curves of RDN and LDN, expressed by operative time, and explore the risk factors for longer surgeries.

As a secondary study aim, we further analyzed perioperative outcomes focusing on intra- and postoperative complications and reporting major recipient outcomes.

Perioperative Management and Follow-Up

All donors underwent thorough preoperative evaluation before kidney donation, as described in Kidney Disease: Improving Global Outcomes guidelines.[19]

Contrast-enhanced computed tomography scan was routinely performed for preoperative anatomical study, and the nondominant kidney was selected according to scintigraphy analysis and kidney volume calculation.[20] In the case of functional equivalence, both centers preferentially selected the left kidney because of the longer vein length. Multiple arteries did not represent an absolute contraindication for kidney selection.

Urinary catheters and surgical drains were usually removed within the first and second postoperative day (POD), whereas oral intake was allowed from POD 0. Parenteral fluid support was usually discontinued on POD 1.

Donor creatinine values were monitored daily until patient discharge, which occurred after complete recovery of feeding, bowel movements, and mobilization.

Intraoperative (ie, bleeding, hollow/solid organ injury, graft injury) and postoperative (ie, wound complication, chylous fistula, pleural effusion, pneumonia, fever requiring antibiotics, bleeding) complications were recorded and graded according to the Clavien-Dindo classification.[21]

After discharge, all the patients underwent regular follow-ups, including renal function tests and blood pressure monitoring at least annually, according to current guidelines.[19]

Surgical Procedure

Robotic Technique

Niguarda's totally robotic technique for living donor nephrectomy has already been described.[22] Briefly, the donor is placed in completely lateral 90° decubitus and the first surgical step consists in a cutaneous Pfannenstiel incision, followed by the detachment of the subcutaneous layer toward the umbilicus and a Kustner fascial incision. A 12-mm optical paraumbilical trocar is therefore placed under manual control, and the mini-laparotomy is closed with a running suture within which an Endo Catch is placed. After pneumoperitoneum creation, 2 robotic trocars are placed into the ipsilateral anterior axillary line, in the subcostal and flank region, respectively, and another

12-mm assistant laparoscopic trocar is placed at the lateral side of the suprapubic incision. Three robotic arms are used during the procedure, using 1 monopolar hook for dissection, a bipolar forceps, a large Hem-o-lok applier, a round-tip scissor, and, when necessary, a needle holder and/or a second bipolar forceps. In right kidney donations, an additional robotic trocar is placed under the xiphoid to lift the right liver and facilitate dissection.

After vascular and ureteral dissection, the kidney is placed in the Endo Catch after cutting the ureter. The vessels are stapled and sectioned with a mechanical stapling device (Signia, Covidien), and the kidney is removed in an Endo Catch through the Kustner incision. After fascial closure, the hemostasis of the operating field and the trocars accesses is checked laparoscopically.

Laparoscopic Technique

The previously published pure laparoscopic technique was used in all left nephrectomies[23]; a modified hand-assisted approach was used for right nephrectomies at the beginning of the experience, with the introduction of the left hand of the leading surgeon through a Pfannenstiel incision at the end of the procedure, with the aim to lift up the right kidney at the time of vessels stapling to obtain a longer renal vein. Such an approach was gradually abandoned with growing surgical experience, shifting toward a totally laparoscopic technique.

The donor is positioned in a 45° lateral decubitus, and the periumbilical optical trocar is placed with an open technique. Two additional 10-mm trocars are placed in the midclavicular line and a third 5-mm trocar is in the flank. Surgical dissection is done through monopolar hook and scissors, bipolar forceps, and a radiofrequency sealer/divider (Ligasure, Medtronic). The renal vessels are sutured with a 30-mm stapling device (Endo GIA, Medtronic), and the kidney is extracted in an Endo Catch through a Pfannenstiel incision.

Statistical Analysis

Continuous data were reported as median and interquartile range; categorical data were reported as counts and percentages.

Comparisons between RDN and LDN groups were performed using the Wilcoxon signed-rank test for continuous variables, the chi-square test or Fisher exact test for categorical variables, and the Cochran-Armitage trend test for ordinal variables.

The surgeon experience (number of performed procedures) was calculated by ordering chronologically the dates of surgery, from the earliest to the latest, separated for RDN and LDN.

Associations between operative time and preoperative risk factors, including surgeon experience, were evaluated with univariable and multivariable linear regression models, separated for RDN and LDN groups.

The interaction terms between each risk factor and the surgical technique were included in the linear models to test the heterogeneity of the effect of the risk factor among surgical techniques.

Learning curves of RDN and LDN were reported plotting the operative time (min) of the chronologically ordered procedures, together with SDs.

To evaluate the evolution of operative times among the 2 procedures, a spline regression model with 2 knots, at the fiftieth and the hundredth procedure, was estimated on the first 154 cases for both procedures. The interaction term between the surgical technique and the surgeon experience was included in the model to test for different evolution among the 2 techniques.

A cumulative sum (CUSUM) analysis of operative time was performed. Among each of the 2 surgical techniques, the CUSUM of the first procedure was the difference between the operation time for the first case and the mean operation time of the respective technique. The CUSUM of the second procedure was the previous case's CUSUM added to the difference between the operation time for the second procedure and the mean operation time of the respective technique. This recursive process continued until the CUSUM for the last procedure was calculated. CUSUM curves of RDN and LDN were reported plotting the CUSUM operative time (min) of the chronologically ordered procedures.

A P value of <0.05 was considered statistically significant.

All the analyses were performed with the statistical software SAS version 9.4 (SAS Institute, Cary, NC).

RESULTS

Study Population

One hundred ninety-three robotic and 410 laparoscopic donor nephrectomies were performed between January 2010 and December 2021 in Milan and Padua centers, respectively.

As already stated, all the procedures consecutively performed by 2 senior surgeons (A.G. and L.F.) starting from the beginning of their experience with RDN and LDN were selected to analyze the learning curves and compare the intra- and postoperative outcomes of the 2 techniques. A total of 39 RDN and 52 LDN performed by other surgeons were excluded, resulting in a final population of 154 robotic and 358 laparoscopic consecutive donor nephrectomies (Figure 1).

Study Group Characteristics

Baseline characteristics of the study population are depicted in Table 1.

We highlighted a significantly higher donor age (56 versus 52; $P=0.004$), lower preoperative hemoglobin (13.3 versus 13.7 g/dL; $P=0.002$), and creatinine clearance (92.2 versus 101.0 mL/min; $P<0.001$) in robotic donors compared with laparoscopic population.

We also depicted a higher prevalence of arterial variations (36.4 versus 22.4%; $P=0.001$) in the RDN cohort.

Learning Curves

Focusing on the evolution of operative times, we depicted a faster decrease in surgery duration in the first 50 RDN cases compared with the first 50 LDN cases ($P=0.0002$), and a faster decrease between the 50th and the 100th procedure in the LDN group ($P<0.0001$). The surgery duration trend was not statistically different between the 2 techniques after the 100th procedure ($P=0.078$). Conversely, comparing the first 154 cases,

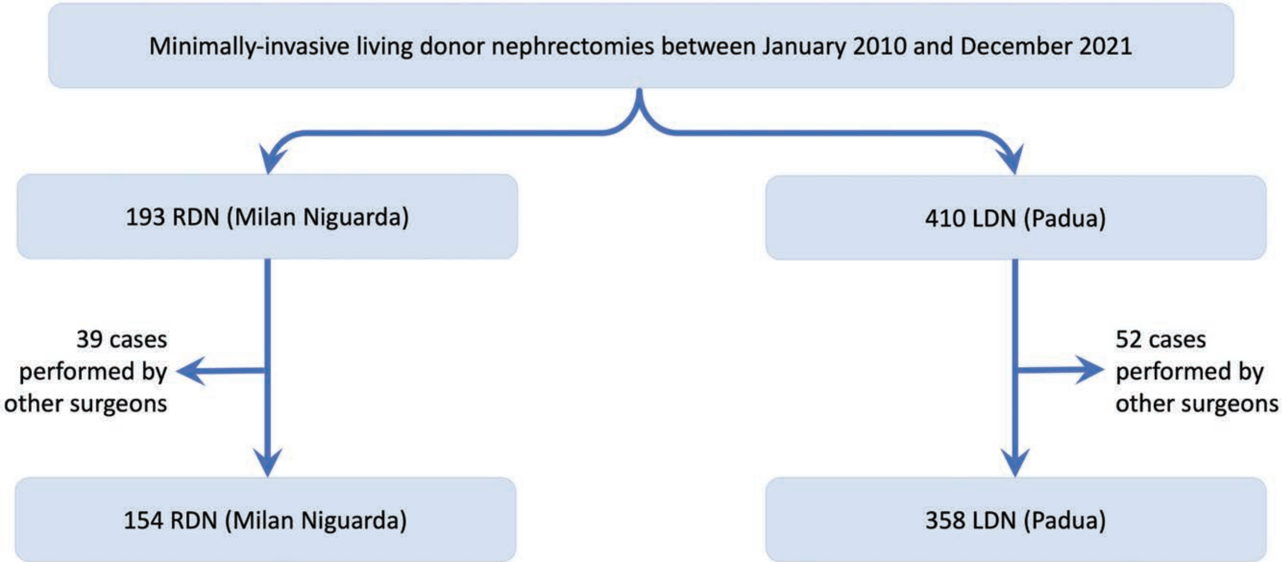

FIGURE 1. Flowchart for patient selection. LDN, laparoscopic donor nephrectomy; RDN, robotic donor nephrectomy.

TABLE 1.

Demographic and clinical characteristics of donor populations (N = 512)

Variable	Level	RDN (N = 154)	LDN (N = 358)	*P*
Age (y), median (IQR)		56 (50–61)	52 (47–60)	0.004
Sex, n (%)	F	109 (70.8)	260 (72.6)	0.67
	M	45 (29.2)	98 (27.4)	
BMI (kg/m^2), median (IQR)		24.9 (22.3–28.3)	24.7 (22.4–27.2)	0.34
Kidney, n (%)	Right	20 (13.0)	68 (19.0)	0.099
	Left	134 (87.0)	290 (81.0)	
Previous abdominal surgery, n (%)	Yes	88 (57.2)	180 (50.3)	0.15
	No	66 (42.8)	178 (49.7)	
Creatinine preoperative (mg/dL), median (IQR)		0.80 (0.70–0.91)	0.76 (0.65–0.88)	0.016
Hemoglobin preoperative (g/dL), median (IQR)		13.3 (12.5–14.0)	13.7 (12.9–14.5)	0.002
Cl. Creatinine Cockcroft-Gault, median (IQR)		92.2 (74.2–110.8)	101.0 (85.2–117.7)	<0.001
Arterial vascular anomalies, n (%)	Yes	56 (36.4)	80 (22.4)	0.001
	No	98 (63.6)	278 (77.6)	
Venous vascular anomalies, n (%)	Yes	17 (11.0)	36 (9.8)	0.68
	No	137 (89.0)	322 (90.2)	

BMI, body mass index; IQR, interquartile range; LDN, laparoscopic donor nephrectomy; RDN, robotic donor nephrectomy.

global trends were statistically different among RDN and LDN ($P = 0.0003$; Figure 2).

Mean and SD of operative time in the 4 quartiles of surgeon experience for RDN and LDN were also calculated: the first quartile (procedure 1–39) had a mean operative time of 279 min (SD = 78) in RDN and 282 min (SD = 28) among LDN. In the RDN cohort, mean operative time dropped to 210 min in both the second (procedure 40–77, SD = 42) and the third (procedure 78–116, SD = 44) quartiles and to 188 min (SD = 47) in the fourth quartile (procedure 117–154). Conversely, in the LDN cohort, mean operative time dropped to 260 min in the second quartile (SD = 45), to 214 min in the third quartile (SD = 36), and to 191 min in the fourth quartile (SD = 24; **Table S1, SDC,** http://links.lww.com/TP/C750 and **Figure S1, SDC,** http://links.lww.com/TP/C750). Performing a linear regression model with operative time as a dependent variable and quartiles of surgeon experience, surgical technique, and the interaction between them as independent variables, the interaction parameter was statistically significant, denoting a different trend between techniques ($P = 0.002$).

Considering the CUSUM analysis of operative time, the turning point of the CUSUM curve was after about 50 procedures among RDN patients and after about 100 procedures among LDN patients (Figure 3). These points detected a change in individual surgeon's performance, where a surgeon with no experience in RDN and LDN techniques, respectively, could complete the initial learning phase.

Analysis of Risk Factors for Longer Surgeries

Table 2 summarizes the univariate and multivariate models for the assessment of risk factors for longer surgeries in RDN and LDN cohorts. Univariate and

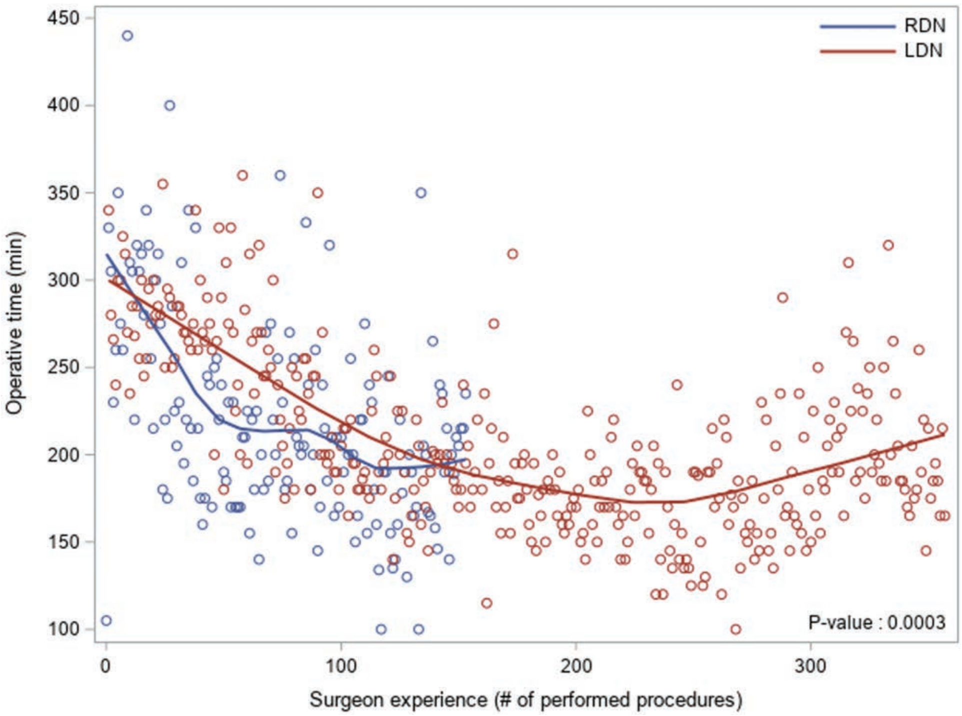

FIGURE 2. Operative time and number of previous procedures, divided by minimally invasive technique. LDN, laparoscopic donor nephrectomy; RDN, robotic donor nephrectomy.

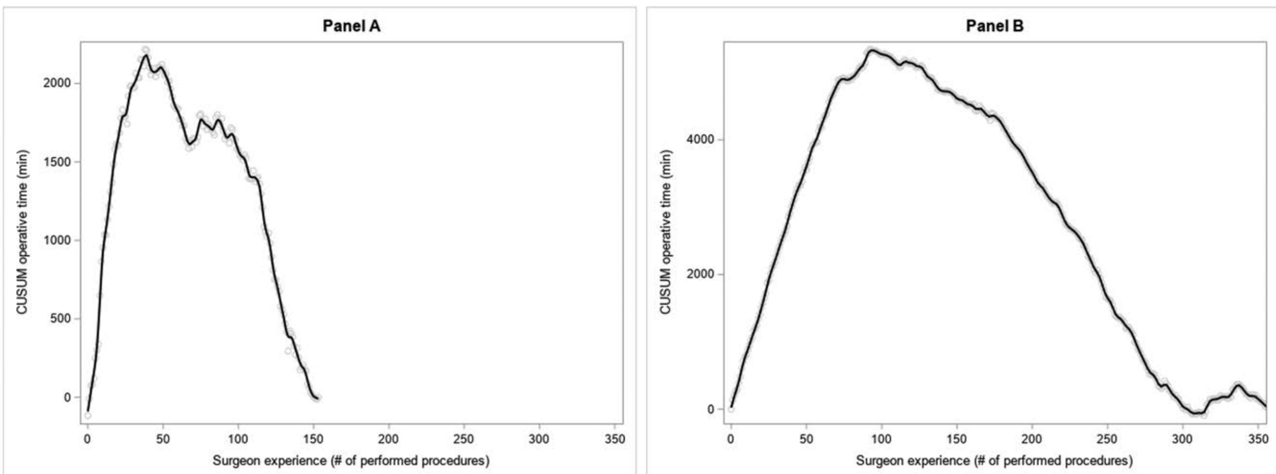

FIGURE 3. The CUSUM analysis of operative time (minutes) among RDN (A) and LDN (B). CUSUM, cumulative sum; LDN, laparoscopic donor nephrectomy; RDN, robotic donor nephrectomy.

multivariate β values indicate the expected increase in the operative time (in minutes) associated with the variable of interest.

Higher body mass index resulted as an independent risk factor for a longer operative time in both RDN (multivariate β associated with 1 kg/m^2 increase: 3.14 [standard error {SE} 1.23]; $P = 0.012$) and LDN (multivariate β: 1.89 [SE 0.57]; $P = 0.001$); multiple arteries significantly prolonged operative time in LDN (multivariate β: 14.1 [SE 4.62]; $P = 0.002$), whereas RDN (multivariate β: –2.27 [SE 9.85]; $P = 0.82$) was not significantly affected by multiple vessels handling; conversely, RDN was significantly longer in right kidneys (multivariate β: 32.6 [SE 15.3]; $P = 0.035$), whereas the procurement side did not exert any significant impact on LDN (multivariate β: 7.89 [SE 5.01]; $P = 0.12$). Both RDN (multivariate β for 50–99 performed procedures versus <50: –59.3 [SE 11.9]; $P < 0.0001$; multivariate β for ≥100 performed procedures versus <50: –76.8 [SE 11.9]; $P = 0.001$) and LDN (multivariate β for 50–99 performed procedures versus <50: –37.1 [SE 7.37]; $P < 0.0001$; multivariate β for ≥100 performed procedures versus <50: –93.7 [SE 5.46]; $P < 0.0001$) were shortened by growing surgical volume. Once again, RDN determined a most rapid decrease in the operative time within the first 100 procedures compared with LDN, whereas surgery duration showed a steeper trend in the LDN after the 100th case (heterogeneity *P*: 0.003).

TABLE 2.

Association between operative time (min) and preoperative risk factors, among RDN and LDN patients (N = 512)

Variable	Level	RDN (N = 154) Univariate β (SE)	Univariate *P*	Multivariate β (SE)	Multivariate *P*	LDN (N = 358) Univariate β (SE)	Univariate *P* Value	Multivariate β (SE)	Multivariate *P* Value	Heterogeneity *P*[a]
BMI	+1 kg/m^2	3.47 (1.37)	0.012	3.14 (1.23)	0.012	1.06 (0.80)	0.19	1.89 (0.57)	0.001	0.098
Kidney	Left	Ref.		Ref.		Ref.		Ref.		0.43
	Right	1.34 (15.5)	0.93	32.6 (15.3)	0.035	13.2 (6.71)	0.051	7.89 (5.01)	0.12	
Previous abdominal surgery	No	Ref.		Ref.		Ref.		Ref.		0.32
	Yes	−9.05 (10.6)	0.40	−0.07 (9.58)	0.99	1.58 (5.33)	0.77	2.30 (3.80)	0.54	
Arterial vascular anomalies	No	Ref.		Ref.		Ref.		Ref.		0.43
	Yes	2.86 (10.8)	0.79	−2.27 (9.85)	0.82	12.0 (6.35)	0.060	14.1 (4.62)	0.002	
Venous vascular anomalies	No	Ref.		Ref.		Ref.		Ref.		0.40
	Yes	−8.84 (16.6)	0.60	−2.09 (15.8)	0.89	5.55 (8.87)	0.53	0.29 (6.47)	0.96	
Surgeon experience (number of performed procedures)	<50	Ref.		Ref.		Ref.		Ref.		0.003
	50–99	−53.1 (11.4)	<0.001	−59.3 (11.9)	<0.001	−39.7 (7.17)	<0.001	−37.1 (7.37)	<0.001	
	≥100	−71.8 (11.2)	<0.001	−76.8 (11.9)	<0.001	−93.7 (5.56)	<0.001	−93.7 (5.46)	<0.001	

[a]*P* value testing the difference of each risk factor effect, estimated by the univariate β, among surgical techniques.

BMI, body mass index; LDN, laparoscopic donor nephrectomy; RDN, robotic donor nephrectomy; SE, standard error.

Intraoperative and Postoperative Donor Outcomes

Intra- and postoperative outcomes after RDN and LDN are summarized in Table 3.

No open conversions were reported, whereas operative time (210 versus 195 min; $P = 0.011$) and warm ischemia time (WIT; 230 versus 180 s; $P < 0.001$) were significantly longer in RDN.

Moreover, intraoperative complications seemed more frequent during RND versus LDN (3.9 versus 0.6%; $P = 0.011$).

The incidence of postoperative complications did not significantly differ between robotic and laparoscopic populations (8.4% versus 11.5%; $P = 0.31$), whereas RDN resulted in shorter hospital stay (4 versus 5 d; $P < 0.001$).

Graft and Recipient Outcomes

Table 4 reports the recipient outcomes of the 2 study cohorts: no significant differences were detectable in terms of delayed graft function, rejection, vascular or ureteral complications.

Creatinine values were significantly higher on POD 1 (4.12 versus 3.68 mg/dL; $P = 0.041$) and POD 3 (1.52 versus 1.33 mg/dL; $P = 0.006$) among recipients from an RDN graft, although creatinine levels at discharge were not statistically different between the 2 cohorts.

DISCUSSION

Minimally invasive donor nephrectomy represents the gold standard for living donor kidney donation[24,25] and has exerted a significant effect on the development and implementation of living donor programs since its introduction in the mid-90s.[5] More importantly, both the safety and the feasibility of LDN have been extensively documented, as proven by the widespread application of this minimally invasive approach to kidney donation.[26]

The development of the DaVinci robotic platform and its pioneering application to living kidney donation from the Chicago group at the beginning of the 20th century[8] represented another milestone of minimally invasive living kidney donation.

Compared with LDN, the diffusion of RDN was partially impaired by its higher costs[10,11] and the relatively limited advantages compared with traditional laparoscopy[12,13]: in fact, there is no clear evidence of any clinical benefit of robotic over the laparoscopic approach to living kidney donation from the current literature.

Although the clinical advantages of laparoscopic over open approaches on postoperative course after living donation were strikingly evident since the introduction of LDN,[6] the comparison of 2 minimally invasive approaches such as RDN and LDN results in a challenging research field.

In fact, considering that living donation is performed on healthy individuals and that minimally invasive approach grants low postoperative morbidity regardless of the technique, it becomes clear that retrospective comparison of RDN and LDN would hardly highlight any significant difference in terms of patient-oriented outcomes, unless performed on a very large population. In contrast, a robotic platform could provide other advantages compared with laparoscopy, such as the usage of EndoWrist instruments

TABLE 3.

Perioperative donor outcomes (N = 512)

Variable	Level	RDN (N = 154)	LDN (N = 358)	P
EBL (mL)	Median (IQR)	20 (20–20)	50 (0–50)	0.23
Intraoperative transfusion, n (%)	Yes	1 (0.6)	0 (0.0)	0.30
	No	153 (99.4)	358 (100.0)	
Operative time (min), median (IQR)		210 (180–254)	195 (170–240)	0.011
Console time (min), median (IQR)		95 (80–120)	–	–
Length of hospital stay (d), median (IQR)		4 (3–5)	5 (4–5)	<0.001
Conversion, n (%)	Yes	0 (0.0)	0 (0.0)	1.00
	No	154 (100)	358 (100)	
Intraoperative complications, n (%)	Yes	6[a] (3.9)	2[b] (0.6)	0.011
	No	148 (96.1)	356 (99.4)	
Donor warm ischemia time (s), median (IQR)		230 (193–275)	180 (138–200)	<0.001
Recipient warm ischemia time (min), median (IQR)		39 (35–44)	37 (32–43)	0.13
Postoperative complications, n (%)	Yes	13[c] (8.4)	41[d] (11.5)	0.31
	No	141 (91.6)	317 (88.5)	
Clavien-Dindo, n (%)	0	141 (91.6)	317 (88.5)	0.49
	1	7 (4.5)	14 (3.9)	
	2	3 (1.9)	26 (7.3)	
	3	2 (1.3)	0 (0.0)	
	3a	0 (0.0)	1 (0.3)	
	4a	1 (0.6)	0 (0.0)	

[a]Three bleedings, 1 solid organ injury, 1 graft injury.
[b]Two bleedings.
[c]One bleeding, 3 chilous fistulas, 2 ileus, 1 rhabdomyolisis, 1 transfusion, and 5 wound complications.
[d]One airway obstruction, 3 chilous fistula, 4 fever, 3 pleural effusion, 18 mild pneumonia, 2 transfusion, and 10 wound complication.
EBL, estimated blood loss; IQR, interquartile range; LDN, laparoscopic donor nephrectomy; RDN, robotic donor nephrectomy.

TABLE 4.

Recipient outcomes (N = 512)

Variable	Level	RDN (N = 154)	LDN (N = 358)	P
DGF, n (%)	Yes	4 (2.6)	4 (1.1)	0.22
	No	150 (97.4)	329 (98.9)	
Acute rejection, n (%)	Yes	13 (8.4)	32 (8.9)	0.84
	No	141 (91.6)	326 (91.1)	
Vascular complications, n (%)	Yes	4 (2.6)	5 (1.4)	0.46
	No	150 (97.4)	353 (98.6)	
Ureteral complications, n (%)	Yes	6[a] (3.9)	4 (1.1)	0.073
	No	148 (96.1)	354 (98.9)	
Creatinine d 1 (mg/dL), median (IQR)		4.12 (3.13–5.36)	3.68 (2.75–5.19)	0.041
Creatinine d 3 (mg/dL), median (IQR)		1.52 (1.09–2.36)	1.33 (1.02–1.83)	0.006
Creatinine d 7 (mg/dL), median (IQR)		1.23 (0.89–1.58)	1.25 (1.01–1.60)	0.24
Creatinine at the discharge (mg/dL), median (IQR)		1.35 (1.00–1.71)	1.31 (1.06–1.63)	0.62

[a]Four ureteral tears, 2 anastomotic leaks.
DGF, delayed graft function; IQR, interquartile range; LDN, laparoscopic donor nephrectomy; RDN, robotic donor nephrectomy.

that facilitates suturing and knotting, stable 3-dimensional visualization of the operative field, and higher surgeon comfort[14]: such benefits are difficult to measure objectively and rely on surgeons' feedback, but could potentially affect surgical learning curve.

Given this scenario, our study aim was to compare the learning curves and the perioperative outcomes of RDN and LDN performed by 2 high-volume Italian centers, providing the largest comparative study that has been performed to date.

The analysis of the baseline characteristics of the RDN and LDN cohorts showed higher creatinine and lower hemoglobin values in the robotic arm, probably related to higher donor age in the RDN cohort. More importantly, we highlighted a statistically significant difference in the prevalence of multiple arteries between the RDN and LDN cohorts: despite both centers selected usually the nondominant kidney to preserve long-term donor kidney function, the prevalence of multiple arteries was significantly higher in the RDN compared with LDN donors, coupled to a slightly higher prevalence of left kidneys in the RDN group, although not statistically significant. Such data suggest an interesting difference toward kidney selection between the 2 centers, which might be justified by the type of minimally invasive approach: in fact, improved vessel handling provided by the robotic devices allows an easier and safer vascular dissection and may therefore affect a higher rate of multiple arteries in the RDN cohort, balanced by a higher prevalence of left kidneys, with a longer vein, that facilitates graft implantation in the recipient.

It is interesting to point out that the 36.4% prevalence of arterial variations in the presented RDN group exceeds the recently reported 24.1% proportion from the largest RDN cohort from the Chicago group.[27] In contrast, the 18.8% prevalence of arterial variations in the LDN cohort did not differ from those reported from other large laparoscopic series.[28,29]

The analysis of the evolution of the learning curves highlighted a significantly faster drop in RDN duration during the first 50 cases, which also represented the turning point of the robotic CUSUM curve, confirming the added benefit of the robotic platform in surgical training, similar to other branches of minimally invasive surgery.[30]

A second step of the analysis focused on the evaluation of determinants for longer surgeries, yielding interesting data that deserves further discussion.

Firstly, the detrimental effect of higher body mass index on the operative times of both RDN and LDN is linked to the need for longer dissection for ureteral and vascular isolation as well as the increased difficulty of a narrow operative field.

Interestingly, the above-mentioned facilitation of multiple vessel handling through a robotic platform was also supported by the analysis of the impact of multiple arteries on operative times, which significantly affected LDN, but did not show any detrimental effect on RDN duration. Conversely, right kidneys were significantly related to increased operative time in the RDN group: once again, such data might be explained by the preferential choice of left kidneys in the robotic arm, regardless of the number of arteries, which was also reported in other robotic series,[31] and may also be linked to lower experience in right kidney procurements in the RDN cohort.

RDN was associated with longer operative and WITs compared with LDN. Such difference is easily explained by the docking and de-docking phases in RDN that increase surgery duration and kidney extraction times: interestingly, the longer donor WIT did not significantly affect graft recovery, as documented by the comparable creatinine values at recipient discharge. Notably, recipient WIT did not significantly differ among the 2 cohorts.

Another relevant finding of our analysis was represented by the significantly low postoperative complication rate after both RDN and LDN, which confirmed the high safety of minimally invasive kidney donation: more importantly, postoperative complications were mostly graded as type I/II according to the Clavien-Dindo classification, with only 4 patients experiencing a clinically relevant complication in the whole cohort. Last, the observed 8.4% and 11.5% postoperative complication rates are actually lower than those reported in other large minimally invasive series,[32,33] supporting the high quality of the participating centers.

Last, postoperative length of stay was slightly shorter in the RDN cohort (4 versus 5 d; $P < 0.001$), but such difference does not appear as clinically relevant and probably relies on different postoperative management of kidney donors between the 2 centers.

Although we did not have any available data concerning costs, such a particular aspect deserves further reflection. Several studies have already shown that robotic-assisted nephrectomy is associated with higher costs compared with laparoscopy.[10,11] This difference results from cost estimations that considers the expensive costs of purchasing the robotic platform, machine maintenance, and the need to use disposable devices. Indeed, for a better comparison, overall costs should include not only operative costs, but also those related to patient hospitalization, days out of work after surgery, patient's perceptions, and surgical impact on the quality of life. As already proven by other authors,[34] RDN granted a faster recovery and shorter length of hospital stay compared with the LDN in such a retrospective cohort.

Moreover, RDN provided a significantly shorter learning curve compared with LDN and seems able to make young surgeons independent in the procedure quickly. This advantage might result in an increase in the number of trained surgeons for donor nephrectomy, an improvement, and broadening of the technique in more transplant centers, and it is hoped that it turns into a decrease in the waiting time for living donor KT. Under this perspective, RDN could actually exert a positive impact on public health costs. Lastly, costs for robotic surgical technique are expected to decrease in the next future with the implementation of new robotic platforms entering the market and competing with the Da Vinci machine.[35]

The main limitations of this study are represented by its retrospective nature and its bicentric enrollment, which might affect both selection and indication biases (as already discussed). In contrast, this analysis represents one of the largest comparative studies focusing on minimally invasive kidney donation that has been published to date and supports the safety and feasibility of both RDN and LDN.

In conclusion, the robotic approach shows a faster learning curve compared with LDN and seems to improve multiple vessel handling. Moreover, both RDN and LDN provided an excellent safety profile with low morbidity rates.

Such results support the feasibility of both procedures and might encourage the wider application of RDN, especially in those centers at the beginning of their minimally invasive approach to living donor nephrectomy.

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